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PROJECT DELIVERABLE REPORT

Introducing advanced ICT
and Mass Evacuation Vessel design
to ship evacuation and rescue systems

D8.6 PALAEMON Consolidated Pilots Evaluation

A holistic passenger ship evacuation and rescue ecosystem

MG-2-2-2018

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Abbreviations

DSS	Decision Support System
EVPDI	Evacuation Pathway Decision Indicator
EVRTI	Evacuation Response Time Indicator
EVTRI	Evacuation Travel Time Indicator
GA	Grant Agreement
ICT	Information and Communications Technology
IRTI	Incident Response Time Indicator
ISM	International Safety Management Code
KPI	Key Point Indicator
LSA	Life Saving Appliances
LSAEMBI	LSA Embarkation Preparation Time Indicator
MCPTT	Mission Critical Push to Talk
MEV	Mass Evacuation Vessel
MS	Muster Station
MSC	Maritime Safety Committee
PIMM	PALAEMON Incident Management Module
PMS	Person Management Service
PTT	Push to Talk
RTLS	Real Time Location Service
SA	Standalone
SEM	Smart Evacuation Management
SRAP	Smart Risk Assessment Platform
TRL	Technology Readiness Level
UI	User Interface

Executive Summary

The PALAEMON project has set its sights on conducting two full end-to-end trials involving genuine end-users in two different European cities (Spain and Athens). In the Athens pilot site, four use cases that pertain to an incident on board the ELYROS vessel that necessitates the mustering of passengers and their readiness for embarkation will be implemented. To ensure a competent response to the incident, the PALAEMON SEM approach will be employed, which involves coordinating the crew, directing the passengers from their initial location to a safe area, and handling any unforeseen passenger issues.

The purpose of the pilot was twofold: to test the SEM approach in a real-world setting and to gather network, service, and performance KPIs to evaluate the approach against a set of predefined criteria. This deliverable is part of WP8, which focuses on testing the integrated SEM ecosystem through the pilot and driving the evaluation of the trial results, specifically T8.6 Pilot evaluation, Lessons Learnt, Recommendations, and Best Practices. The aim is to ensure that the pilot meets the requirements gathered from other WPs and to collect evaluation results from the field trials release.

This deliverable provides an overview of the PALAEMON Smart Evacuation Management approach, including its functional, operational, and technical requirements. Moreover, it provides the basic building blocks for the SEM evaluation procedure that will guide the pilot site during the validation process, including KPIs definition, data collection, data analysis, and evaluation against the KPI targets.

To evaluate the SEM approach, the first step is to comprehend the needs associated with executing the trial at SEM pilot sites and define a set of pilot use cases. The next step is the actual execution of the pilot use cases on the pilot site, which involves preparing the sites by deploying the appropriate technologies, deploying the necessary network functionalities, and preparing the environments for the test execution. Then, the pilot use cases are carried out, and the required metrics are collected. Finally, the collected metrics are analyzed and evaluated against a set of predefined criteria.

The deliverable concludes by evaluating the level of satisfaction of end-users and verticals players with the use cases deployed. This includes feedback from the vertical players who participated in the final pilot run.

1 Introduction

This is the Deliverable entitled "PALAEMON Consolidated Pilots Evaluation: SEM Trial", part of PALAEMON WP8 "Application Field Trials, Evaluation and Outcomes", the last Work Package of the project. WP8 was about the pilot application of the main project achievements, as they have been summarized in the Deliverables of the following WPs:

- WP4: PALAEMON Mass Evacuation Vessel
- WP5-WP6-WP7 (WP5: PALAEMON on-board mustering tools and services - WP6: PALAEMON Back-End Infrastructure - WP7: PALAEMON Integrated System and Technology Validation Trials.

In essence, as described in the GA, the pilot activities should prove the feasibility and maturity of the outcomes of previous WPs through demonstration and testing in a relevant ship environment. Since the project has the two-fold objective of developing:

a) A mass centralized evacuation system, "based on a radical re-thinking of Mass Evacuation Vessels (MEVs)" and,
b) An intelligent ecosystem of critical components "providing real-time access to and representation of data to establish appropriate evacuation strategies for optimising the operational planning of the evacuation process on damaged or flooded vessels",

the pilot action has been implemented in two locations, under different settings:

I. In Spain, in the shipyard of Astander, a key Consortium participant, where the PALAEMON MEV construct has been tested through simulations and trails in close sea
II. In Greece (Port of Piraeus), where an operational version of PALAEMON Data Ecosystem supporting the needs of the evacuation operations has been successfully deployed onboard of a passenger ship provided by ANEK Lines, an international shipping company, operating in the South of Europe, and end-user member of the Consortium (ELYROS F/B).

As a result, the work in WP8 has been splitted into two parts, carried out by different actors and under different demonstration and testing principles. Consequently, the reporting on WP8 piloting action has been also organized in two groups of deliverables:

WP8 Deliverables - Series A (MEV)	PALAEMON Application Field Trials, Evaluation and Outcomes - Mass Evacuation MEV
WP8 Deliverables - Series B (SEM)	PALAEMON Application Field Trials, Evaluation and Outcomes - Smart Evacuation Management | SME (where the term Smart Evacuation Management refers to the operational version of PALAEMON Data Ecosystem

In short, the Deliverables of WP8 are segregated in two distinct groups, the first reporting to the MEV pilot action and the second one to the SEM pilot, as shown in the following tables (Table 1, Table 2 respectively).

Table 1. WP8 Deliverables - Series A (MEV)

WP8 Deliverables - Series A (MEV)					
#	**Deliverable Title**	Lead beneficiary	Type	Dissemination level	Due Date[1]
D8.1a	Report on Pilot Sites Preparation and Assessment: MEV Trial		R	Confidential	M44
D8.2a	Operational Pilot Sites: MEV Trial		R	Confidential	M44
D8.3	PALAEMON application trial 1: MEV Trial		R&DEM	Confidential	M44
D8.6a	PALAEMON Consolidated Pilots Evaluation: MEV Trial		R	Public	M44
D8.7a	Operation Manual, Recommendations and Best Practices: MEV Trial		R	Public	M44
D8.8a	Public release WP8: MEV Trial		R	Public	M44

Table 2. WP8 Deliverables - Series B (SEM)

WP8 Deliverables - Series B (SEM)					
#	**Deliverable Title**	Lead beneficiary	Type	Dissemination level	Due Date[2]
D8.1b	Report on Pilot Sites Preparation and Assessment: SEM Trial	UAEGEAN	R	Public	M44
D8.2b	Operational Pilot Sites: SEM Trial	UAEGEAN	R	Public	M44
D8.4-5	PALAEMON application trial 2 and 3: SEM Trial	UAEGEAN	R&DEM	Public	M44
D8.6b	PALAEMON	UAEGEAN	R	Public	M44

[1] See Second GA amendment
[2] See Second GA amendment

	Consolidated Pilots Evaluation: SEM Trial				
D8.7b	Operation Manual, Recommendations and Best Practices: SEM Trial	UAEGEAN	R	Public	M44
D8.8b	Public release WP8: SEM	UAEGEAN	R	Public	M44

The Deliverable that follows is the **“edition SEM"** of the **Deliverable “PALAEMON Consolidated Pilots Evaluation”**, and the **fourth of the Series B (SEM) of the WP8 Deliverables** (submitted subsequently to D8.1b, Report on Pilot Sites Preparation and Assessment: SEM Trial) [1], D8.2b (Operational Pilot Sites: SEM Trial) [2] and D8.4-5 PALAEMON application trial 2 and 3: SEM Trial) [3]. It gathers the evaluation results of the field trial to provide the proof that the deployed pilot effectively meets the functional, operational and technical requirements described in WP2 and in other WPs. D8.6b is a key outcome of the Task 8.6 “Pilot evaluation, Lessons Learnt, Recommendations and Best Practices” (M34-M44), which essentially focused on producing:

a) Evaluation metrics for the KPIs (Key Performance Indicators) defined in T8.2 and reported in Deliverable D8.2b [2] and other metrics for accepted performance levels of the SEM platform, which have been defined in collaboration with the end-users.
b) Impact assessment indicators for accuracy, cost, operational effectiveness, security performance and the overall reliability and trustworthiness of the proposed SEM platform solution.
c) Score sheets for the evaluation of pilots scenarios/exercises.
d) Qualitative evaluations from industry practitioners and the end-users[3]

In more detail, this Deliverable includes the following chapters:

Chapter 2 gives a short summary of the SEM pilot deployment (Trial) and how it meets the functional, operational and technical requirements described in WP2 and in other WPs (WP5-WP6-WP7).

Chapter 3 presents the different evaluation metrics obtained during the implementation of SEM pilot (Trial).

Chapter 4 includes an analysis of the qualitative input provided by practitioners and the end-users.

Chapter 5 presents an impact analysis of the SEM platform to appreciate its application potential.

[3] The Task 8.6 has also delivered the project lessons learnt, as far as PALAEMON Smart Evacuation Platform is regarded, and recommendations for future actions, which are all included in D8.7b “Operation Manual, Recommendations and Best Practices Guide”.

2 PALAEMON Smart Evacuation Management: functional and technical-operational evaluation

This chapter provides a summary of how the SEM pilot deployment meets the functional, operational and technical requirements described in WP2 and in other WPs (WP5-WP6-WP7). In WP2[4], WP5, WP6 and WP7[5], a rich ecosystem of ICT modules was designed on the basis of a series of requirements that PALAEMON must satisfy. Under WP8 an operational version of this ecosystem had to be deployed on F/B ELYROS for piloting. Several core ICT components were deemed suitable for deployment (the SEM platform) generating a specific set of scenarios/exercises that have been supported by the platform. These scenarios, presented in detail in previous Deliverables[6] , served as the basis for the design and organization of Project Piloting Activity within Work Package 8.

As a result, the PALAEMON Smart Evacuation Management (SEM) is a subset of the PALAEMON Ecosystem (D7.7 WP7 public release [5]) and is designed to provide cutting-edge technology-aided support to the evacuation process on passenger ships. It offers a platform for efficient evacuation management, which improves and augments existing procedures with new functionality and tools. It is designed to provide a holistic vision for the evacuation management of passenger ships, by enabling semi-automated process management, monitoring, and decision support of the emergency inspection, mustering and embarkation process. The SEM platform consists of specific process management and automation modules which are integrated to implement the necessary functionality and were deployed for piloting onboard ELYROS F/B together with a 5G Standalone (SA) mobile network, a Wi-Fi 6 network and an array of BLE beacons (to provide indoor positioning and way finding capabilities with significant accuracy). Users interact with the system using 5G enabled mobile phones, connected to the 5G SA network deployed on the vessel, equipped with Passenger and Crew specific mobile apps (which are part of the SEM platform). The SEM platform has been deployed on-board a passenger ship (ELYROS Ferry) and tested as the Deliverable 8.4-5 reported [3].

[4] D2.5 Final version of PALAEMON Use Cases Definition & Operational Requirements [4]

[5] D7.7 WP7 Public release (contains the results form WP5, WP6) [5]

[6] D8.2 Operational Pilot Sites: SEM Trial [2], and D8.4-5: PALAEMON application trial SEM (Greece) [3] see also ANNEX 1

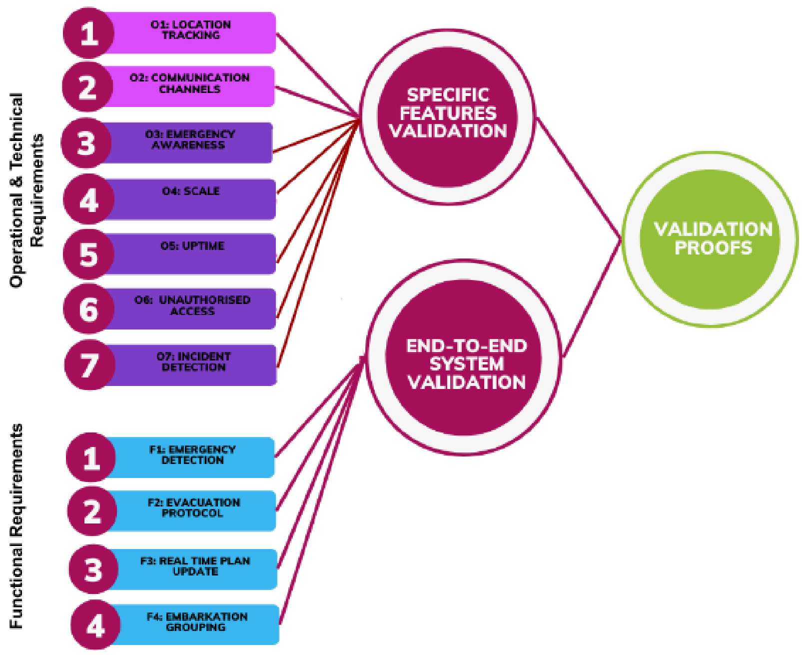

Figure 1. SEM functional, operational and technical requirements validation

The successful pilot implementation has been followed by a thorough evaluation of the technical/operational performance and the functionality of the SEM platform.

In fact, the platform was evaluated, under realistic conditions, with a two-step process.

- Initially, the **operational and technical requirements** of the platform were validated by verifying **"specific features"** of the platform that implement them.
- Next, the platform's **functional requirements** were validated using an **end-to-end scenario implementing a complete evacuation flow** (a supposed fire accident which creates the need of launching the mustering process and leads to the eventual evacuation of the vessel), essentially validating that the SEM platform achieved TRL5 status[7]. The SEM platform had earlier achieved TRL 4 status (technology validated in the lab) for the modules that implement the core features of the platform architecture (the functionality of the Wireless Network has been simulated through a passenger location simulator which takes in consideration the specificities of the ship's structure, decks, staircases etc., while for cell communications in the lab a typical 4G connection was used)[8].

In the next sections, the operational and technical requirements of the SEM platform as well as its functional requirements are validated by providing **proofs of validation** in the form of screenshots and/or videos depending on the type of the requirement being validated.

[7] TRL 5: The technology is validated in relevant environment (industrially relevant environment in the case of key enabling technologies); see: [h2020-wp1415-annex-g-trl_en.pdf (europa.eu)]
[8] WP5-Task 5.4; see: https://www.linkedin.com/feed/update/urn:li:activity:6988199764802580480

2.1 SEM Operation Validation

The following section defines in detail the operational and technical requirements of the SEM platform which have been integrated in the SEM core product architecture, in the form of “specific features”, and their validation proofs.

2.1.1 Operational and technical requirements integrated in the SEM platform

Operational and Technical requirements refer to the non-functional requirements that the SEM platform must satisfy in order to **operate effectively and efficiently**. These requirements are concerned with the **performance**, **usability**, and **maintainability** of the system. In other words, operational and technical requirements are focused on how the system operates, rather than what it does. Additionally, the operational requirements include technical specifications such as the performance, reliability, and security of the system. For the SEM platform, operational and technical requirements have been defined as follows:

1. **O1**: the ability to support **location tracking** of passengers and crew with **significant accuracy** and near **real-time** location update times.
2. **O2**: the ability to provide **efficient and reliable communication channels** between the bridge, the passengers and the crew during an emergency situation with **minimal setup times and latency**.
3. **O3**: the ability to **improve** the passengers' emergency **awareness** and the time necessary for them to **identify** their assigned **muster station**.
4. **O4**: the ability to **scale to handle large number of concurrent passengers** and crew members and **high volumes of data.**
5. **O5**: the ability to monitor the health of the platform to **ensure a high level of uptime** and be able to operate continuously without downtime for extended periods of time.
6. **O6**: the ability to **prevent unauthorized access** to sensitive user data.
7. **O7**: the ability to minimize the time required for locating missing/trapped/injured/disabled passengers (passenger **incident detection)** and optimizes the **resource allocation**.

The SEM platform has been carefully designed to meet the above non-functional requirements by:

- Ensuring the deployed “sensing infrastructure (Wi-Fi Access Points, beacons etc.), coupled with Real Time Location (RTLS) system, provides the necessary accuracy and update times.
- Implementing an emergency evacuation messaging protocol which improves the passengers’ awareness and minimizes the identification of the path towards the mustering stations.
- Developing efficient communication channels between the bridge and the crew which provide the required latency and setup times via a private 5G SA network.

- Enabling horizontal and vertical scalability, making it capable of handling a large number of users while maintaining performance and stability, due to the platform's micro service architecture.
- Setting-up an access control policy designed to maintain data security and privacy by limiting sensitive information exchange to only authorized services, following industry best practices (OAuth2.0 resource flows)[9].

2.1.2 Operational Proofs of Validation

The SEM platform was validated to ensure it met its operational and technical requirements. Under these actions the following requirements were validated.

Table 3. Requirements Validated under Specific Feature Validation Actions

#	Requirements Validated	Type
1	**O1**: the ability to support **location tracking** of passengers and crew with **significant accuracy** and near **real-time** location update times	Operational
2	**O2**: the ability to provide **efficient and reliable communication channels** between the bridge, the passengers and the crew during an emergency situation with **minimal setup times and latency**.	Operational
3	**O3:** the ability to improve the passengers' emergency awareness and the time necessary for them to identify their assigned muster station.	Operational
4	**O6**: the ability to **prevent unauthorized access** to sensitive user data	Operational
5	**O7**: the ability to minimize the time required for locating missing/trapped/injured/disabled passengers (passenger **incident detection)** and optimize the **resource allocation**.	Operational

Validation proofs are provided in the form of screenshots or videos depending on the specifics of the feature validated. In detail message validation proofs consist of two screenshots. One from the recipient's mobile device and one from the SEM platforms logging service[10]. For example, the validation proof of the bridge successfully transmitting a multimedia message to the mobile app of a client (identified via the ticket number A862050) consists of the following two screenshots:

[9] See the Deliverables of WP5 (PaMEAS component)

[10] The SEM platform logging service is a specifically built service to capture system logs for validation purposes.

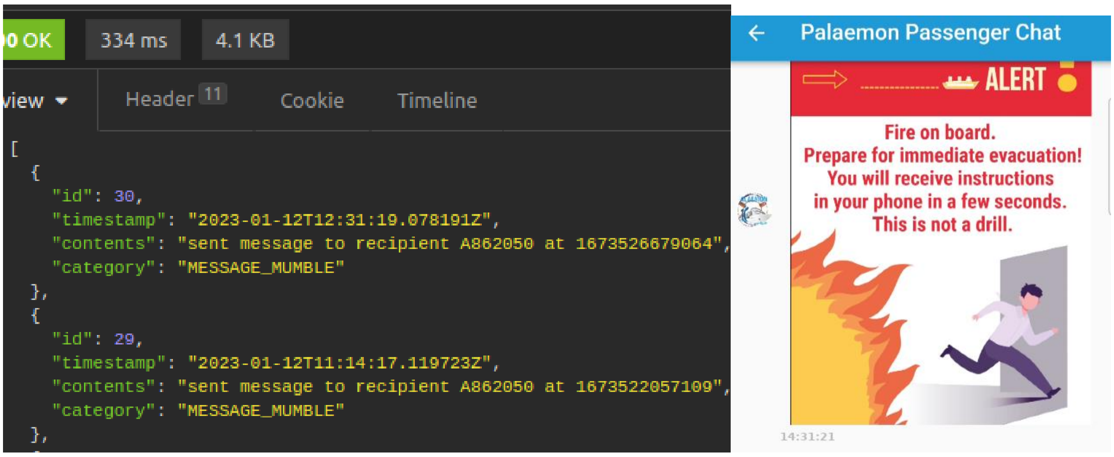

Figure 2. SEM platform multi-step validation process

The following table (Table 4) contains 13 validation proofs of specific key features of the SEM platform, including a description of each such feature, its accompanying validation proof, a description providing context to the aforementioned proof and finally the targeted functional or operational requirement implemented by this feature. The operational requirements related to the capacity of the system to support real time location of passengers and crew (O1) and ability to establish emergency low latency communication channels between the bridge, crew and passengers are the key stone requirements of the platform. As a result, several validation tests for these requirements were conducted and their proofs are presented in the following table (Table 4).

Table 4. Emergency Communication Channel Functionality Validation

Specific Features	Description	Proof of Validation (1-13)	Proof Description	Targeted Req.
Location & identification of a Passenger	Validate the capacity of the SEM platform to verify the location of a passenger[11]	Video 1	• Video of bridge SEM platform UI tracking passenger & crew members on a cabin and corridor of Deck 9	O1
Location & identification of a Crew member	Validate the capacity of the SEM platform to verify the location of a crew member[12]	Video 1	• Video of bridge SEM platform UI tracking passenger & crew members on a cabin and corridor of Deck 9	O1
Passenger moves from one Geofence	Validate the capacity of the SEM platform	Video 1	• Video of bridge SEM platform UI tracking passenger moving	O1

[11] Specifically within a cabin, whose width is less than 3 meters
[12] Specifically within a narrow corridor, whose width is less than 2 meters

to another	to monitor the real time location of a passenger moving inside the pilot areas of ELYROS		from a cabin to a corridor and back to a cabin	
Crew moves from one Geofence to another	Validate the capacity of the SEM platform to monitor the real time movement of a passenger moving inside the pilot areas of ELYROS	Video 1	• Video of bridge SEM platform UI tracking a crew member moving from a cabin to a corridor and back to a cabin	O1
Passenger moves with variable speed, performing a U-turn	Validate the capacity of the SEM platform to monitor the movement of a crew member abruptly changing her direction, moving with various speeds (walking, running)	Video 1	• Video of bridge SEM platform UI tracking passenger leaving the Muster Station, moving down a corridor, stopping and returning to the MS	O1
Bridge to Passengers messaging	Validate the ability to instantly transmit a multimedia message to a specific passenger[13]	Screenshot 1 Screenshot 2	• Screenshot of systems log of sending the message • Screenshot of mobile app receiving the message	O2
Bridge to Crew messaging	Validate the ability to instantly transmit a multimedia	Screenshot 1 Screenshot 2	• Screenshot of systems log of sending the message • Screenshot of mobile app receiving the message	O2

[13] This validation proof offers also verification of the latency of generating and transmitting alert and notification messages via the SEM platform. The definition of message latency in a network is the total time taken for a complete message to travel from one device to another across a network. https://www.geeksforgeeks.org/performance-of-a-network/

	message to a specific crew member			
Passengers to Bridge	Validate the ability of a passenger sending free text the bridge	Video 1	• Video of Bridge UI receiving the message “I need help” from a passenger	O2
Passengers to Bridge voice communication	Validate the ability of a passenger to send an audio message to the bridge	Video 1 Video 2	• Video recording of passenger sending audio message • Video recording of bridge receiving audio message	O2
Bridge to Crew voice communication	Validate the ability of the bridge to initiate a PTT channel with a crew member	Video 1	• Video of bridge ordering crew to assume emergency posts via PTT and crew responses.	O2
Crew to bridge video communication	Validate the ability of a crew member to stream video to the bridge	Video 1	• Video of crew member streaming live video to the bridge using their PALAEMON crew app	O2
Passengers awareness	Validate contribution to passengers' emergency awareness and identification of muster station	Screenshot 1	• Screenshot of emergency alert messages received by passengers • Screenshot of passenger mustering instructions received on their mobile phones	O3
User Registration	Validate the protection of personal information from unauthorised access	Screenshot 1	• Screenshot of a complete user profile generated in the system with the personal identification information encrypted	O6
Passenger at risk	Validate the ability to minimise the time required for locating	Video 1	• Video of SEM platform UI indicating the detection of a passenger issue and suggesting the	O7

	missing/trapped/injured/disabled passengers		allocation of a suitably trained crew member	

Validation proofs for O4 (scalability) and O5 (uptime) are not presented in the table above (Table 4). Due to restrictions to the pilot actions, only a few passengers at each action were participating. As a result, scalability using real passengers onboard ELYROS was not studied, however the scalability of the platform was validated using simulation software to mimic the movement of hundreds of passengers and the results are presented in detail in D8.1b (see also ANNEX 2). In detail, scalability testing was performed to validate that the SEM platform was ready for deployment on ELYROS for emergency evacuation situations. The simulation testing ensured that the SEM platform could handle a large volume of location data generated by hundreds of passengers moving inside the spaces of ELYROS during the mustering process, generate correct mustering instructions for the passengers based on their current location, and provide accurate passenger counts and identification in assembly stations via user-friendly UIs. To verify the proper functionality of the SEM platform under load testing, specific software was developed (PaMEAS Passenger Location Simulator) to simulate the movement of passengers on board the ship. The software was used to simulate the movement of 700 passengers on board the decks of ELYROS and validate key functional requirements of the SEM platform (However, we must note here that the PaMEAS Passenger Location Simulator was not designed to measure the effect of the SEM platform on the evacuation process or evaluate the effectiveness of the evacuation plan implemented by the SEM platform. Its sole purpose is to evaluate the scalability of the SEM platform infrastructure with respect to being able to handle the real-time location of hundreds of passengers and provide them with the correct alerts and mustering instructions, as well as enable the Master to have a clear overview of the progress of the evacuation in real time).

Furthermore, to ensure maximum uptime and minimal downtime industry standard techniques were employed. Indeed, specialized monitoring software[14] has been installed to generate instant alerts via different channels in case of system failure.

2.2 SEM Functional Validation

This section presents Functional Requirements of the SEM platform as well as their validation proofs.

2.2.1 Functional requirements to evaluate the SEM platform

2.2.1.1 Initial designs goals and functional requirements

The design and development of the SEM platform has been initiated by a detailed review of the literature ([6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16]). As the implementation of the SEM platform progressed, these designed goals matured to the

[14] Prometheus https://prometheus.io/ and Grafana https://grafana.com/

platform's functional requirements. The following set of objectives essentially defines the main design and development goals of the SEM platform (as they derive from WP2, WP5, WP6 and WP7):

Table 5. SEM Platform Initial Design Goals

1. **D1**:To demonstrate the ability to prioritize and use the resources and assets within the constraints of the pilot development on a specific area of a passenger ship
2. **D4**: To demonstrate the ability to conduct rapid situational reassessment when a disruptive (to evacuation) accident occurs
3. **D2**: To demonstrate the ability to locate trapped or injured passengers and crew in ship's sweeping (cleared) zones.
4. **D3**: To demonstrate the ability to provide immediate assistance to meet the needs of trapped or injured passengers and crew
5. **D5**: To demonstrate the ability to provide accurate passenger counts and identification in assembly stations
6. **D6**: To demonstrate the ability to collect and readily communicate information to the bridge and the land-based control authorities during emergency operations.
7. **D7**: assist with the embarkation process

Functional requirements define the behavior of a system, software, or product. They are specific actions that the system must perform in order to achieve its objectives. Once the SEM platforms design and implementation were solidified the design goals presented above matured to the functional requirements listed below.

Table 6. SEM Platform Functional Requirements

SEM Platform Functional Requirements		Design Goals
F1	Improve and augment the processes related to the **detection and inspection of emergencies**. This includes the triggering of alarms on the bridge, assisting with the dispatching of the emergency inspection teams, **assisting with the evaluation of the situation** based on the existing regulations, external inputs (such as weather conditions) and calculations of risk assessments.	D1, D6
F2	Improve the management **of the evacuation protocol**. Specifically, this requirement involves the (semi-)automation of the ordering of the crew to assume their emergency posts, and the alerting of the passengers. Furthermore, the system must **improve the mustering process** (by assigning muster stations to passengers and guiding them to them). Additionally, the system should handle the identification and **optimize the assistance of passengers in distress**.	D2, D4, D5, D6

F3	**Monitor the mustering process** in real time and accordingly update/optimize **the active evacuation plan** if necessary. This involves updating mustering instructions and closing muster stations and evacuation routes (if necessary) in a semi-automated manner, as well as **identifying trapped passengers and assisting passengers who request**	D1, D2, D3
F4	**Assist the embarkation process through the organization of evacuees in groups, as a preparation action before they embark on life-saving appliances (LSAs)**. This involves forming groups and notifying them for evacuation, reducing the friction between passengers and crew in such a way that ensures passengers are organized into groups as fast as possible, reducing passenger group hopping (for example due to searching for travelling partners).	D7

2.2.1.2 SEM Platform functional requirements realization

It is clear that the functional requirements of the SEM platform include all originally envisioned design goals and furthermore impose additional requirements for the SEM platform to implement. In detail to meet these requirements, the SEM platform triggers **alerts** to the bridge once an incident is detected and displays appropriate **advice** on how to address the emergency based on international regulations, while at the same time calculates **risks assessments** and displays them as additional advice on specifically built UIs. Additionally, the platform maintains a mission critical push to talk (**MCPTT**) infrastructure to enhance the coordination capacities between the crew members and the bridge. Furthermore, the SEM platform enhances the mustering process by providing the necessary infrastructure to improve passenger emergency awareness through **direct personalized alert messages** and **personalized mustering instructions** based on the current location of passengers, which are tracked in real time. The instructions sent to passengers are customized based on their specific characteristics, such as preferred spoken language or medical condition and their current location. Also, to further optimize the mustering process it enables the creation of **instant communication channels** between crew and passengers. Additionally, the platform provides the necessary **visualization tools** to enable the bridge to manage the whole process from a single UI triggering the appropriate actions as the emergency situation evolves.

Moreover, the platform enables the bridge to monitor and update the emergency protocol according to the data received in real time. Specifically, the SEM platform automatically detects and locates passengers that require assistance with the evacuation and furthermore enables passengers to instantly request assistance with the tap of a button. It optimizes the utilization of the ship's resources by recommending optimal **assignments of crew member teams to passenger incidents** based on their current location, training, and the location of the incident. Furthermore, the SEM platform via appropriate UIs notifies the bridge for potential issues with escape routes or mustering stations and enables the bridge with the tap of a button to exclude these areas for the evacuation plan. Additionally, in case of such updates the SEM platform notifies all passengers and crew members of the changes guiding them according to the alternative plan activated.

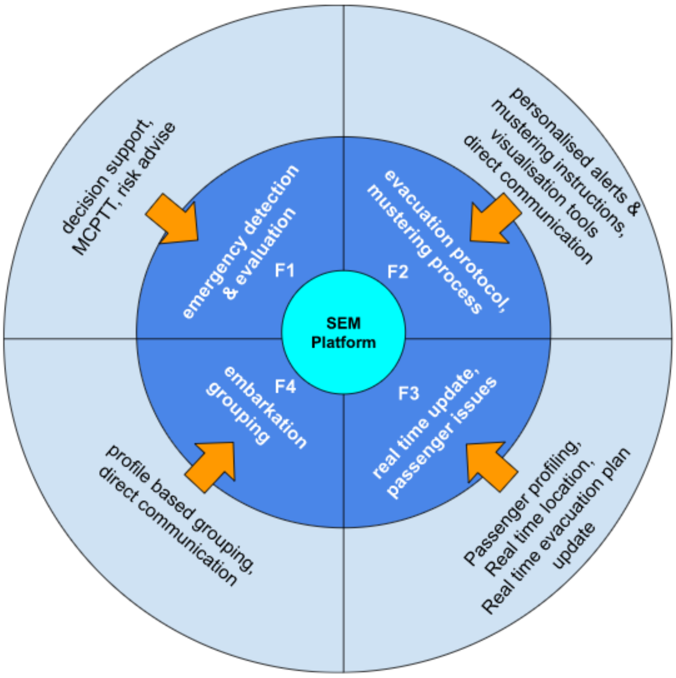

Figure 3. SEM Platform functional requirements realization

Finally, it supports the embarkation process by assigning passengers to groups based on their profiles, such as family members or people travelling together. This aims to minimize incidents of passengers switching queues, which can cause confusion and stall the embarkation process at a critical time.

2.2.2 Functional Proofs of Validation

The validation actions presented in the previous section ensures that the deployment of the SEM platform onboard ELYROS meets the necessary operational and technical requirements to support the functionality of the SEM platform.

Table 7. Requirements Validated using End-to-End System Functionality Validation

#	Requirements Validated	Type
1	**F2**: improve the management **of the evacuation protocol**. Furthermore, the system must **improve the mustering process**. Additionally, the system should handle the identification and **optimize the assistance of passengers in distress**.	Functional

4	**F1**: support, improve and augment the processes related to the **detection and inspection of emergencies**.	Functional
6	**F3: monitor the mustering process** in real time and accordingly update/optimize **the active evacuation plan** if necessary	Functional
9	**F4**: **assist the embarkation process** through the organization of evacuees in groups, as a preparation action before they embark on life-saving appliances (LSAs).	Functional

The next step in the validation process of the SEM platform was to ensure that it meets the functional requirements of the system. For this reason, a detailed **validation flow** was developed and was executed on board ELYROS by expert users. As a result, after the execution of this validation the system was verified to:

1. contain all major elements needed (deployed on ELYROS)
2. implemented all the necessary UI for the users to interact with
3. implemented all necessary functions to support the whole lifecycle of the evacuation process.

Effectively, after the end of this validation activity the SEM platform achieved Technology Readiness Level (TRL) 5[15] (functionality testing by expert users in a relevant environment - F/B ELYROS). Finally, the flows which are presented in the following section were executed using expert users[16] assuming the roles of passengers and crew members as needed.

The overarching validation flow used to verify the SEM platform was the following:

A fire is detected on Deck 5, triggering alarms on the main SEM platform UI (PIMM component) monitored by the bridge. The bridge uses the MCPTT integrated system (PaMEAS/Tactilon - Agnet Works) to order the investigation of the incident. Upon arrival, the teams are unable to contain the fire. Using the recommendations generated by SEM

[15] TRL5 is defined as "Technology validated in relevant environments (industrially relevant environment in the case of key enabling technologies)"23. This means that the technology has been tested and verified in a realistic setting, such as a laboratory or a field site, and has shown to meet the expected performance and reliability criteria. https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

[16] An expert user is someone who has a high level of knowledge and skills in a specific domain or field, and who can perform complex tasks efficiently and effectively1. When validating TRL5, an expert user can help to evaluate the technology in a relevant environment and provide feedback on its usability, functionality, reliability, and performance. https://link.springer.com/article/10.1023/A:1009839827683

platform's decision support and risk assessment modules (DSS and SRAP[17], respectively), which are displayed on the main UI (PIMM), the bridge decides to alert the passengers and have them muster at the piloting area Muster Station located on Deck 9 (MSB). During mustering, some of the passengers' health becomes critical[18]. The SEM platform detects this and automatically proposes crew members (trained for dealing with medical incidents and in the closest proximity to the passenger) to assist (recommendations displayed on PIMM). The bridge authorizes these assignments, and the crew members are notified via MCPTT. Eventually, the passenger issue is resolved. Furthermore, as the fire progresses, smoke is detected in a corridor area, making it inaccessible. The bridge decides to close this area (via the PIMM UI) and the SEM platform updates the instructions sent to the passengers, sending the appropriate directions. Additionally, the SEM platform informs the crew members of the deviation from the original mustering plan. As the situation deteriorates further, the SRAP component recommends abandoning the ship to the bridge (displayed on PIMM). The bridge evaluates the situation, verifies that mustering is completed (via PIMM and MCPTT), and decides to proceed with the embarkation of the passengers to the LSA. The SEM platform notifies the passengers on how to proceed, complementing the instructions of the crew members on site.

This verification was implemented by validating the following actions implemented as a series of separate pilot flows.

Table 8. Functional validation actions and flows

Validation Flows
Registration flow: Passenger and Crew Registration via PALAEMON People Management System (PMS)
Emergency Situation Assessment (two actions - three flows) Act 1.1: Emergency Inspection Flow 1.1.1 - Handling of a smoke alarm Flow 1.1.2 - Handling emergency Inspection Act 1.2: Emergency Reconnaissance Flow 1.2.1 - Handling situation evaluation (Crew team arrives on the Incident location | Crew reports back | Situation is evaluated)
Activation of evacuation protocol - Alerting passengers (one action - one flow) Act 2.1: Activation of evacuation protocol - Alerting passengers Flow 2.1.1 - Handling activation of Evacuation protocol | Handling crew notification about evacuation launch | Handling passengers alerting

[17] The exact way SRAP is functioning is presented in the deliverables D3.9 Development of Risk Assessment Platform (V1) [25] and D3.10 Development of Risk Assessment Platform (V2) [26].

[18] Mocked data is used for simulate this behavior as it is not possible to induce a critical medical condition on a subject.

Mustering (three actions - four flows) Act 3.1: Mustering in progress Flow 3.1.1 - Handling passenger notifications (All systems in mustering mode) Flow 3.1.2 - Handling passengers mustering instructions Act 3.2: Mustering update - Closing of an Area Flow 3.2.1 - Handling update of evacuation plan (Mustering instructions update) Act 3.3: Incident Management Flow 3.3.1 - Handling passengers at risk (identification, crew assignment)
Embarkation (two actions - two flows) Act 4.1: Mustering Completed flow 4.1.1 - Handling decision to abandon the ship Act 4.2: Organization of evacuees in groups flow 4.2.1 Handling group formation and notification for evacuation

Finally, during these validations the following artificers were used:

- Integration with Ship Legacy Systems. The SEM platform has not been integrated with the legacy alerting infrastructure onboard ELYROS. As a result some interactions between these systems are mocked
- Firefighting efforts: As is to be expected an actual fire was not set onboard F/B ELYROS and as a result the efforts by the crew to contain it were also mocked
- Passenger Health Issue: As it is not possible to generated fake biometric data for the passengers wearing the PALAEMON SmartBracelet to generate a passenger issue, the functionality of the SOS button of the SmartBracelets was used instead (this button generates an identical alert to the SEM platform marking the passenger in need of medical assistance - indistinguishable from a drop in biometrics).
- Fire progression: Once again since a real fire would be extremely dangerous any data with respect to the progression of the fire on the vessel are mocked.

The results of the validation are presented in the next table (Table 9). Specifically, for each flow of the aforementioned actions validation proofs in the form of either screenshots or appropriate video was gathered pointing to the **specific functional requirement** the specific flow validates[19]. Again, validation proofs are presented in the form of screenshots or videos depending on the specific action being validated.

[19] These flows were defined so as to validate the functional requirements of the SEM platform. As a result, they reflect all the capabilities of the system and are presented as part of an end-to-end validation process. It is only natural for these flows to be very closely related to the pilot scenarios and exercises presented in ANNEX 1. The pilot scenarios were designed to faithfully mimic the progression of an emergency incident (that the SEM platform supports end to end) and the flows to validate the functional capacities of the platform (which again support the progression of the incident end to end). For example, Flow 3.1.1 - Handling passenger notifications is closely related with episodes Must_311, Must_312, Must_313, Must_314

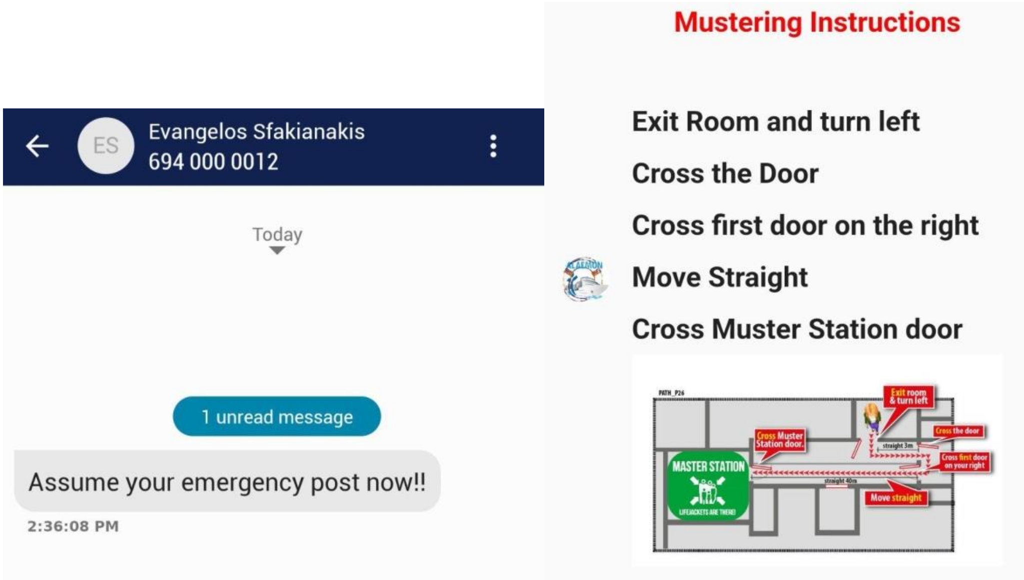

Figure 4. SEM Messaging to Passengers and Crew

Table 9. Validation Proofs

Flow	Description	Proof of Validation	Proof Description	Requirement
Prep Actions	Passenger registers to the system using the SEM PMS Service[20]	Screenshot 1	Screenshot of a complete user profile generated in the system (log) and the PALAEMON Service Card issued to the passenger	F2
Flow. 1.1.1	Smoke Alarm is triggered	Video 1	Video from the SEM platform main UI (PIMM) displaying the triggering of the fire alarm	F1
Flow. 1.1.2	Order for emergency Inspection	Video 1	Video of Master using the SEM UI to initiate a PTT session with the firefighting team	F1
Flow. 1.2.1	Situation evaluation	Video 1 Video 2	• Video of SEM UI tracing the movement of the crew member on Deck 9 • Video of SEM UI of crew streaming live video to the bridge	F1
Flow. 2.1.1b	Crew notification	Screenshot 1	Screenshot of crew members receiving alerts to assume their	F2

[20] The People Management System (PMS) is responsible for the registration of passengers and crew members into the system, creating their complete profiles. For more details please refer to D8.4-8.5

	about evacuation launch		emergency posts	
Flow. 2.1.1c	Alerting passengers	Screenshot 1	Screenshot of emergency alert messages received by passengers	F2
Flow. 3.1.2	Passengers mustering instructions	Screenshot 1	Screenshot of passenger mustering instructions received on their mobile phones	F2
Flow. 3.2.1	Mustering instructions update	Screenshot 1	Screenshot of passenger's updated mustering instructions (after the closing of a specific area of the ship)	F3
Flow. 3.3.1	Identification of passenger at risk	Video 1	Video of SEM platform UI indicating the detection of a passenger issue and suggesting the allocation of a suitably trained crew member	F3
Flow. 4.2.1	Group formation and notification for evacuation	Screenshot 1	Screenshot of passenger's embarkation instructions received on their mobile phones	F4

3 PALAEMON Smart Evacuation Management: performance evaluation

The previous sections dealt with the presentation of validation proofs that the SEM platform met its functional requirements and an end-to-end evaluation (testing) of the SEM platform on the basis of a concrete evacuation process scenario. This section presents the metrics defined and the values measured to assess the performance of the SEM platform on the overall evacuation process.

The IMO "Guidelines for a Simplified Evacuation Analysis for New and Existing Passenger Ships" covered by MSC Circular 1033 and its successor MSC Circular 1238 recommend a maximum allowable total passenger ship evacuation time (n) to be in the range of 60 to 80 minutes based on the following:

- 60 minutes should apply to ships having no more than three main vertical (fire) zones
- 80 minutes applying to ships having more than three main vertical (fire) zones

The evacuation time is analyzed as presented in the following figure (Figure 5).

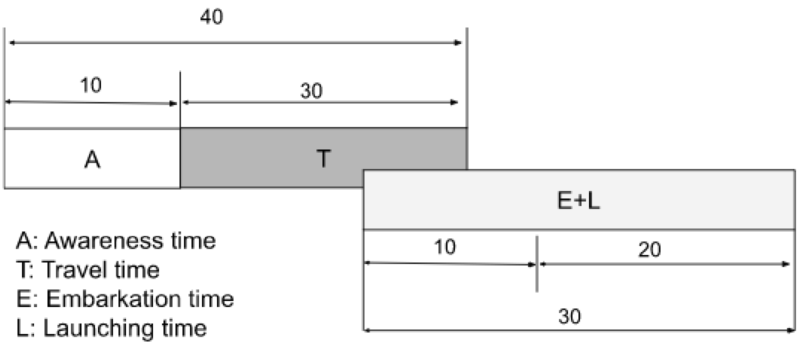

Figure 5. Maximum evacuation time required by IMO regulation [17]

The SEM platform directly affects the time required for the passenger to become aware of the emergency and reach the muster station (A), the Travel time (B), and the Embarkation time (E).

Thus, to measure the effect of the SEM platform on the evacuation time a set of KPIs was defined in D8.2b [2] presented in the following table (Table 10).

Table 10. SEM Platform KPIs

KPI
(EVRTI)
Evacuation Pathway Decision Indicator (EVPDI)
Evacuation Travel Time Indicator (EVTRI)
LSA Embarkation Preparation Time Indicator (LSAEMBI)
Incident Response Time Indicator (IRTI)

However, the piloting space is naturally reduced to a limited area of one ship Deck (Deck 9). This led to a reduction in the number of measurements that could be taken, in a way that ensured a meaningful comparison between the values reported in the literature and the ones that would be gathered in the piloting actions. Specifically:

I. The Evacuation Travel Time Indicator is studied in the literature using advanced simulation software that simulates different characteristics for each passenger (age, speed etc.), for large groups of passengers moving across extensive paths spanning whole decks to reach the muster stations. As a result, measuring in the confined spaces of only part of Deck 9 with less than 20 passengers would not yield accurate or even comparable results in any meaningful way.

II. Similarly, for the times required to prepare for the embarkation on the LSAs (LSAEMBI) the literature uses simulations to study the behaviour of large groups of passengers and it would not be possible to create comparable values with less than 20 subjects.

Even with these restrictions, we were able to measure the following KPIs in a meaningful way:

1. Evacuation Response Time Indicator (EVRTI)
2. Evacuation Pathway Decision Indicator (EVPDI)
3. Incident Response Time Indicator (IRTI)

This is due to the fact that EVRTI and EVPDI deal with the perception of the passengers and their capacity to swiftly follow the evacuation plan of the ship (Awareness time: A). The Awareness time (A) is directly dependent according to the literature [18][17] on the time required for the passenger to comprehend the emergency signals and the time required for the passenger to discover and embark on the appropriate evacuation route. The confined spaces and the restricted number of passengers (per pilot scenario/exercise execution) do not have any significant impact on these measurements and a meaningful comparison with the values reported in the literature is possible.

Finally, the IRTI is a metric that has not been studied thus far in the literature. However, a survey of recent accidents reveals that it plays a key role in the efficiency of the evacuation capacity of a ship, and therefore directly affects the Travel and Embarkation time (T and E). For this reason, this KPI was studied (although a comparison with literature values is not possible).

The rest of this section presents these KPIs as well as the values recorded and ANNEX 3 provides the methodology for each measurement in detail.

3.1 Evaluation metrics used

Evacuation Response Time Indicator (EVRTI) denotes the time required for the passengers to become fully aware of the emergency and react. Specifically, this value is calculated via the time required for the emergency alert to reach the passenger [information Dissemination Time, idis(t)] and the time the passenger needs to PERCEIVE/VERIFY the received emergency information contained in the alert message [Information Perception Time, iper(t)]

$$EVRTI(t) = idis(t) + iper(t)$$

According to the literature the initial “information dissemination rate” (i.e. the percentage of passengers who immediately understand the meaning of the evacuation cue) is 17% [19]. Using this value, the information perception time (iper) is calculated as **39 seconds** [20]. Furthermore, the information Dissemination Time is equal to the duration of the continuous blast of the vessel's whistle in case of fire.

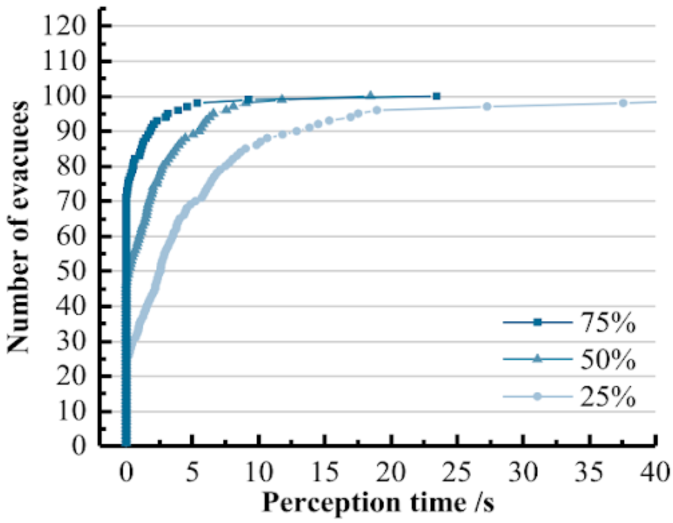

Figure 6. Perception time vs "initial dissemination rate" [20]

As a result, according to the literature the EVRTI prior to the application of the SEM platform is reported as **49 seconds.**

Table 11. EVRTI value from the literature

EVRTI (Passenger Response Time)			Methodology
Information Dissemination Time	Information Perception Time	Total RESPONSE	
10sec	39 sec	49 sec	literature

Evacuation Pathway Decision Indicator (EVPDI) denotes the time required for the passengers to search for information about escape options and develop an escape plan (choose a pathway) that would lead them to the muster station. This value is broken into the time required for ACQUIRING information about the available escape options [pathway information reach time, pireach(t)] and the time needed to PROCESS that information and DECIDE on the evacuation path [pathway decision time, pdecide(t)].

$$EVPDI(t) = pireach(t) + pdecide(t)$$

According to the literature, the process a passenger uses to make a decision on how to reach the muster station depends on several factors, such as their personal characteristics, the surrounding environment, the presence of crew that provides instructions and, in the absence of such instructions, the behavior of neighboring passengers [19] [20] Specifically, the average time between the sounding of the alarm and when passengers start moving to an assembly station, in public spaces or cabins, on a RO-PAX vessel is 158 sec, while in cruise ships the passengers in public spaces respond in 242 sec and in 704 sec when in cabins [18] (thus exceeding the maximum suggested time by IMO). This time includes the aforementioned Evacuation Response Time Indicator. As a result, a a minimum threshold value we use the reported 158 seconds reduced by the EVRTI (resulting in 131 seconds). According to the literature of these 131 secs, 23% correspond to the pathway information reach time (i.e. 31 sec), while the remaining 100 sec is the pathway decision time [19]

Table 12. EVPDI value from the literature

Evacuation Pathway Decision Indicator (EVPDI)			Methodology
Pathway Information Reach Time	Pathway Decision Time	Total RESPONSE	
31sec	100 sec	131 sec	literature

Incident Response Time Indicator (IRTI) denotes the time required to identify and find the position of a passenger requiring special handling or requesting immediate assistance and generating recommendations for the crew (issue an "emergency team action ticket"). It consists of the time needed to detect the incident and inform the Bridge [incident detection time, idetect(t)], the time needed to assign the incident to an appropriate crew member team [incident assignment time, iasgmt(t)] and the time needed by the crew to travel to the incident location [incident travel time, itrav(t)]

$$IRTI(t) = idetect(t) + iasgmt(t) + itrav(t)$$

This time is not studied so far in the literature; however, it can play a critical role in the reduction of the evacuation process as reports from recent accidents suggest that a significant amount of time was allocated in the search of trapped/missing passengers[21].

3.3 Evaluation metrics values (obtained during the pilot action)

Using the evaluation metric methodologies presented in the ANNEX 2 a series of measurements were conducted as part of the piloting actions on F/B ELYROS to validate the efficiency of the SEM platform with respect to its capacity to improve and augment the evacuation management process. Specifically, piloting actions took place on ELYROS F/B:

- On the 15th of December 2022 with the participation of 15 test users. During this action the interaction of the passengers with the SEM platform was evaluated and specifically the reaction of the passengers with respect to receiving alert messages and mustering instructions was measured. Additionally, the

[21] https://www.theguardian.com/world/2022/feb/18/fire-ferry-greece-italy-euroferry-olympia-288-people-on-board

coordination of crew members with respect to investigating an incident, and the execution of the evacuation protocol was validated.

- On the 19th of December 2022 with the participation of 9 test users. During this action the same scenarios as with the 15th of December were repeated. Additionally, the handling of passenger related issues and the handling of the formation of Mustering groups was measured.
- On the 31st of January 2023 with the participation of 9 test users. During this action all of the previous scenarios were repeated with the most updated version of the SEM platform deployed on F/B ELYROS.

Prior to these pilots, pre-piloting exercises took place at the premises of the National Technical University of Athens on the 25th of November 2022. These exercises measured the interaction of the SEM platform with the users with respect to alert and notification messages.

For the execution of the measurements presented in this section three different measurement methodologies were used to measure the user's interaction with the SEM platform:

1. The first methodology used was "**eye-tracking"** software, which tracks user gaze and generates heat maps to identify areas of the screen that users spend the most time on. Participants wear eye-tracking goggles, and experts analyse the resulting video footage to measure the relevant metrics.
2. The second methodology used was "**stopwatch"** measurements, in which trained team members monitored participants' actions and took measurements of relevant metrics in real time. This methodology provided more flexibility and allowed for the monitoring of groups using a single measurement.
3. The third methodology used was "**system log analysis"**, which involved analysing logs generated by the system to extract measurements of specific actions taken by users during the pilot exercise. This methodology was useful for measuring the last piloting action, for which the other two methodologies were not applicable.

These values measured together with the methodology used and date of the piloting action are presented in the following table (Table 13).

Table 13. Metrics measurements for Information Perception Time

EVRTI (Passenger Response Time)						
Information Dissemination Time (mean)[22]	Information Perception Time (mean)	Total RESPONSE Time (mean)	Methodology	Date	Type	No. of subjects

[22] The information Dissemination Time was measured with the stopwatch methodology. Specifically, a measurement was taken the instant the Master pressed the alert passengers

10sec	14.24sec	24.24 sec	eye-tracking	25/11/22	LAB	19
10sec	10sec	20 sec	eye-tracking	15/12/22	Pilot	15
10sec	13.6sec	23.6 sec	stopwatch	19/12/22	Pilot	9

Measurements of the Information Perception Times using the methodology of analyzing the system logs is not possible as the users in this case do not start moving until they receive the mustering instructions and decide on the evacuation path they must take. The **most accurate** of the aforementioned measurements are those taken on the **15th of December** and the **19th of December** as those were executed onboard ELYROS (measurements in a relevant context).

The mean of these experiments gives an approximate **44% percent improvement** of the EVRTI using the SEM platform compared to the values reported in the literature.

Table 14. Metrics measurements for pathway decision time

EVPDI (Passenger Pathway Decision Time)						
Pathway information reach time (mean)[23]	Pathway decision time	Total DECISION Time	Methodology	Date	Type	No. of subjects
15sec	22.59[24]sec	37.59sec	eye-tracking	25/11/22	LAB	19
15sec	9.2sec	26.2sec	eye-tracking	15/12/22	Pilot	15
15sec	10sec	25sec	stopwatches	19/12/22	Pilot	9
15sec	12.67sec	27.67sec	system logs	31/01/23	Pilot	9

Next, as part of the piloting actions the capacity of the SEM platform to improve on the Incident Response Time was measured. The **most accurate** of the aforementioned

button on the SEM platform UI and then the times for the messages arriving at the passengers end devices were recorded. This time doesn't correspond to the SEM platforms latency as it encapsulates apart from the latency the time required to generate the personalized messages for each passenger

[23] The pathway information reach time was measured with the stopwatch methodology. Specifically, a measurement was taken the instant the Master pressed the “Mustering” button on the SEM platform UI and then the times for the mean times of the messages arriving at the passengers end devices were recorded. This time doesn't correspond to the SEM platforms latency as it encapsulates apart from the latency the time required to generate the personalized mustering instructions for each passenger (a time consuming process).

[24] Excluding outlier values of subjects which answered too quickly (under ten seconds answers)

measurements are those taken on the **15th and 19th of December** and the **31st of January** as those were executed onboard ELYROS (measurements in a relevant context).

The mean of these experiments gives an improvement of **over 50% percent** of the EVPDI using the SEM platform compared to the values reported in the literature.

This improvement should be evaluated very carefully as it involves factors which might alter the faithfulness of the results:

1. The piloting was conducted in a restricted space of ELYROS, as a result the mustering instructions transmitted to the passengers were not overly complicated.
2. The passengers were aware that they were participating in a piloting exercise so delays in taking action due to panic were not present.
3. The passengers trusted each other (they were students at the same institution). As a result, once a passenger started moving the rest of the passengers in the same area followed, resulting in essentially only the fastest reaction time in each passenger cluster being recorded.

An interesting observation is that the times required to process the mustering instructions are comparable to the times recorded for the passengers becoming aware of the emergency. This can be explained in the following ways:

- The passengers were already alert and were using their passenger apps once the mustering instructions were transmitted, while with the initial alerts the passengers were relaxed and required some time to reach for their phones.
- The passengers seem to act as soon as they comprehend that the message contains mustering instructions and have understood the first action (e.g. exit the room), re-reading the instructions as they move along down their assigned evacuation routes. As a result, they do not try to memorize or even comprehend the whole instructions contained in the message. They take action the instant they are aware that they need to move. This is particularly important as typically crew members are placed in the evacuation routes to assist passengers and only the initial actions of the passengers are required to ensure a fast evacuation process.

For the above reasons additional measurements of this metric should be made on a larger scale before drawing definitive conclusions.

Table 15. Metrics measurements for Incident Response Time

Incident Response Time Indicator (IRTI)							
Incident detection time	Incident assignment time	Incident travel time[25]	Total Time	Methodology	Date	Type	Data Points

[25] Incident Travel Times are only reported for reference, as the pilot space was restricted and as a result cannot be used to draw concrete conclusions based on this value.

(mean)							
30sec	20sec	1min	110sec	stopwatches	19/12/22	Pilot	3
33sec	19sec	50sec	112sec	stopwatches	31/01/23	Pilot	2

The IRTI is not studied in the literature so far, as a result it is not possible to conduct a comparison based on existing results. However, it is well known that this process takes up a significant amount of time during actual crisis and is handled in an ad hoc inefficient and at time ineffective manner[26] .
The pilot was conducted in a restricted area of Deck 9. As a result, distances that needed to be covered by the crew member to reach the passenger requiring assistance were very small. As such the incident travel time should be taken into consideration. Additionally, in each execution of this scenario only a single passenger required assistance. As a result the measurements for the incident assignment time might not be completely faithful and require further evaluation in a larger scale pilot.

Nevertheless, the measurements (especially for the incident detection time) provide a promising outlook on the application of the SEM platform in the area as well.

The measurements of the incident detection time give an estimation of **33 seconds** for the **detection of incidents** using the SEM platform.

Based on the aforementioned measurements it is clear the SEM Platform **reduces the overall passenger "awareness time"** (by reducing the **EVRTI** - Passenger Response Time, and contributing to the reduction of the **EVPDI** - Passenger Pathway Decision Time). Additionally, due to the fact that using the SEM platform we can expect an "initial dissemination rate" of higher than 75% (all passengers receive instant alerts about the emergency situation) using reference values from the literature [20] presented in Figure 6, we expect an even larger reduction of this value. Of course, large scale pilots are needed to verify the exact value of the reduction of the EVRTI.

Based on the aforementioned measurements it is clear the SEM Platform **reduces the overall passenger "awareness time"** (by reducing the **EVRTI** - Passenger Response Time, and contributing to the reduction of the **EVPDI** - Passenger Pathway Decision Time.

Finally, the exact effect of the application of the SEM platform to the **travel** and **embarkation times** needs to be validated in large scale pilots to draw definitive conclusions about the effect of the application of the platform.

[26] https://www.theguardian.com/world/2022/feb/18/fire-ferry-greece-italy-euroferry-olympia-288-people-on-board

4 PALAEMON Smart Evacuation Management: Qualitative evaluation from industry practitioners and end-users

4.1 Pre-Pilot feedback gathering

The SEM platform underwent, first, an initial round of evaluation with the intent of gathering constructive feedback and improving the system prior to the deployment of the system on ELYROS and the execution of the piloting actions. This feedback was gathered via a remote workshop organized by Johanniter Research and Innovation Centre[27].

To demonstrate a coherent execution flow, simulation software was used to emulate the movement of passengers onboard ELYROS[28]. Using these simulations as bases, key features of the SEM platform with respect to mustering and evacuation were demonstrated (due to the remote nature of this workshop it was not possible to demonstrate the full capabilities of the system). Two expert users (Ragab Ashraf and Cpt. Eberhard Koch), with extensive experience in the maritime industry (both participants were captains with an extensive work experience in the field of cruise ships), participated in the demonstration and provided valuable feedback (which was incorporated to the version of the SEM platform demonstrated at the actual pilot onboard ELYROS).

To assess the prototype of the SEM platform, a combination of observation and the Concurrent Think Aloud method was used. The Concurrent Think Aloud method [21] involves the user giving feedback on the test item while interacting with it, allowing the evaluator to better understand the participant's thoughts, questions, and emotions. Additionally, a survey with qualitative and quantitative elements was designed. After each phase of the evacuation scenario, the participants were asked to answer some open questions.

The gathered feedback was significant and contained many to the point arguments. As a result, it enabled the creation of an improved system which was received very positively by the expert users present at the final pilot evaluation as presented in the following section even if not all recommendations were implemented in time for the pilot.

Specifically, the expert users present at the event made the following key evaluation observations about the presented SEM platform prototype (a complete list of the specific comments of the expert users and how they were addressed prior to the pilot is presented in ANNEX 4):

1. The SEM platform should validate that the advice presented by the Decision Support Module (DSS) are in accordance with the International Safety Management Code (ISM) or the International Convention for the Safety of Life at Sea (SOLAS) regulations.

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[27] On the 21st of November 2022 at the Johanniter Research and Innovation Centre in Vienna.
[28] See D8.1b "Report on Pilot Sites Preparation and Assessment: SEM Trial" [1], chapter 4

2. Information displayed at the SEM platform UIs should be more easily understood with fewer text elements and with bigger fonts being used in all available UIs
3. Advice about the necessary steps to follow as generated by the DSS module should be implemented in the frontend as a checklist enabling the user to check items off
4. The type of the emergency incident should always be visible in the SEM UIs
5. Different flavours of the UIs should be implemented, and accessible based on the different roles of the user in the hierarchy of the vessel (for example, the Master should not be cluttered with the real time location of all passengers).
6. Audio communication should be preferred to text communication channels when interacting with the crew
7. When interacting with the passengers images should be preferred to text information should be kept short and simple
8. The SEM platform should include the functionality to reopen muster stations (previously closed due to the progression of the incident)
9. The status of the mustering and evacuation process should be visible in all UIs
10. Some system states are not one to one applicable in all type of vessels and should be disabled when the SEM platform is deployed on cruise ships

Furthermore, according to the comments of the end users the SEM platform UIs provide a good overview of the situation to the Bridge, but they stressed that the platform must be adapted based on their recommendations before it can be considered for deployment in production settings.

The feedback received by the expert users was taken into very serious consideration from the technical partners and the majority of the proposed changes were incorporated to the version presented at the final pilot evaluation of the system. Specifically, from the previously reported recommendations the following were implemented in time for the pilot actions onboard ELYROS.

Table 16. Expert users recommendation implemented prior to piloting

#	Recommendation
1	Validate that the advice presented by the Decision Support Module (DSS) are in accordance with ISM and SOLAS
2	SEM platform UIs should include fewer text elements and with bigger fonts
3	The type of the emergency incident should always be visible in the SEM UIs
4	Different flavours of the UIs should be implemented, and accessible based on the different roles of the user
5	Audio communication should be preferred to text communication channels when interacting with the crew
6	When interacting with the passengers images should be preferred to text information should be kept short and simple

7	The SEM platform should include the functionality to reopen muster stations (previously closed due to the progression of the incident)
8	The status of the mustering and evacuation process should be visible in all UIs

4.2 End-users feedback gathering during pilot action (trial)

Following the final demonstration of the SEM platform to end-users and industry practitioners via selected pilot exercises on board F/B ELYROS (January 2023), the project advanced to conduct user interviews and evaluate the system. As part of the evaluation process, the end-users were presented with a set of five questions, which are listed below:

Table 17. Expert User Evaluation Questionnaire

	Question
1	What is your background and role in relation to the PALAEMON project?
2	What were the main positive and innovative aspects of the PALAEMON project that you observed during the demonstration?
3	How would you rate the PALAEMON system's integration of data and services on a scale of 0 to 10?
4	How would you rate the PALAEMON system's situation awareness perspective on a scale of 0 to 10?
5	How would you rate the user-friendliness of the PALAEMON system on a scale of 0 to 10?

Additionally, the industry practitioners were consulted on the acceptability of the project by companies and market outlook. Below is a brief summary of their responses (a summary of the answers of the expert users on a per question basis is provided in ANNEX C).

Specifically, with respect to the innovative points of the SEM platform it was noted that the platform can be used to "**efficiently evacuate passengers onboard"**, and provides a possible "**solution to problems that have existed for decades**" in the maritime sector with respect to the management of large numbers of passengers in evacuation situations by offering a "**comprehensive and accurate picture"** of the situation supporting the decision-making process. Furthermore, via its use of "**ultra-low latency**" 5G SA network it enhances and speeds up the evacuation process significantly by providing instant and "**accurate information to the passengers and crew members**". Finally, it was noted that the system has "**potential uses in other sectors**" managing large groups of people.

Additionally, the users evaluated positively the degree of integration of data and services of the SEM platform. Specifically, the users seemed to base their answers on the "**capabilities displayed by the system**" during the pilot. As a result, even though integration with legacy ship IT systems was not possible in this context, the SEM platform demonstrated how it can leverage such future integrations (in a production environment) with success. This led the end-users providing a high score (**8/10**) for the capacities of the platform in this area, pointing out that it can and should be improved in the future.

With respect to the capability for improving the overall situation awareness the industry experts gave a very positive evaluation (approximately **9.5/10**). The end-users mainly focused on the awareness provided to the Bridge/Crew (and did not consider the passengers' side in their answer) and noted that the SEM platform provides "**crucial feedback and information for decision-making**" during emergency situations. They particularly commented positively on the capacity of the SEM platform to instantly identify and monitor the location of the passengers in real-time as well as the support for handling passenger related incidents (trapped/injured passengers) which require "**immediate assistance**".

A very significant evaluation of the SEM platform is its usability. The expert users evaluated positively the usability of the SEM platform, giving it a score of **9/10**, and stated that it "**provides a good overview**" of the necessary information (passenger and crew real time tracking, risk assessments). Furthermore, the industry experts expressed their particular interest in verifying the adoption of the SEM platform by passengers (requiring them to use specific mobile apps and wear bracelets) and noted that they are eager to see such a system rolled out in "**reality in the near future**".

The **interviews** of the expert users were **recorded** and are available at the following link.

The evaluation summary score sheet from the end-users is presented in the following figure (Figure 7).

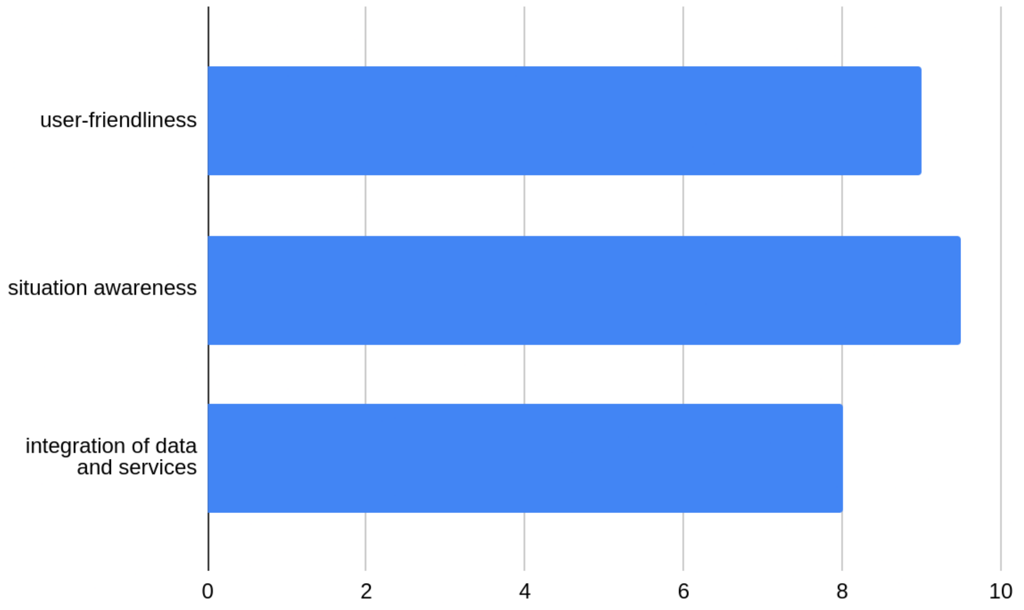

Figure 7. SEM Platform End User mean scores (1 very bad, 10 excellent)

In summary, feedback from experts and end-users in the maritime industry on the PALAEMON project has been positive, with recognition of its potential to improve safety and emergency management procedures. The SEM platform's user-friendly interface and ability to provide a comprehensive and accurate view of emergency situations were highlighted as its most significant strengths. Moreover, the SEM platform's successful end-to-end implementation and trials were acknowledged by industry practitioners, who expressed confidence in its potential for growth in the market in the future.

However, experts have also suggested areas for improvement, such as the integration of more sensors and data sources and the need for validation by organizations and classification societies. Despite these areas for improvement, the PALAEMON project shows promise in providing critical support for maritime emergency situations and could prove to be a valuable tool for managing large groups of people.

Finally, after reviewing the SEM platform the classification society **DNV GL**[29] has provided the following positive evaluation:

> *"The PALAEMON Smart Evacuation Management Ecosystem is aiming at digitalizing the evacuation process. The innovative solutions proposed under the PALAEMON SEME include the utilization of smart and contemporary measures to ensure passenger traceability, coordination and safety, paving the way for future*

[29] https://www.dnv.com/

developments in the evacuation process"

5 PALAEMON Smart Evacuation Management: Impact analysis

The evaluation of the SEM platform in terms of conformanc*e to* the design and development objectives, operational readiness (TRL 5), performance (through three essential KPIs) and acceptance from the end-users and industry experts, is completed with an **impact analysis**.

The project GA mentions a requirement for assessing the impact of the pilot in terms of operational effectiveness -- including security (a task undertaken in previous chapters), accuracy (reported in D8.4-5 [3]), costs and, more generally, evaluating the overall reliability, trustworthiness and suitability of the proposed system solution (Task 8.5).

In fact, when deploying ICT in large projects, a critical task is to conduct a **technology assessment process** in order to evaluate: a) the effective contribution of the proposed technology system to the responsible design, reliable implementation and effective governance [22] and, b) the larger impact such the industrial development of these technologies have on industry's growth and social wealth and well-being [23].

To evaluate the SEM platform in this context and provide the evidence needed to fulfil the evaluation, we have used an impact assessment methodology [23] structuring the impact evaluation framework. It includes the following:

A. Impact Analysis: a) Nature of the impact, b) Relevance of the impact, c) Breadth of impact
B. Baseline environment: a) What is currently in place, b) Stakeholders' attitudes, c) Issues raised in past evacuations
C. Pilot primary and secondary impact objectives
D. Impact scoring

5.1 Impact analysis

Objective: Ensuring that the SEM platform has the potential to be a tangible real-life improvement, beyond research. Ensuring that the deployed software and hardware infrastructure is in line with the vision of those in a position to provide guidance and use the project innovations to change practice. Showing evidence that the SEM platform exploitation plan took steps in all areas to build mutually beneficial and enduring partnerships which achieve positive outcomes.

Reference material: WP2-WP5-WP6-WP7-WP8 Deliverables

Impact assessment via the following criteria:

Nature of the expected impact (defined by the influence, effect, demonstrable contribution,

change, or benefit resulted from the innovation)
- A social benefit, i.e., increased passenger safety, resulted from the adoption of the SEM platform
- A benefit for the whole coastal shipping industry from an evacuation management approach that supports quality/automated safety processes, thus reducing administrative burdens of shipping industry regulation, increasing customer satisfaction and improving customer experience.

Relevance of the expected impact (the context within which impact takes place must be relevant to the requirements of the different stakeholders in terms of providing tangible contributions to solving the stakeholders' problems)
- Provision of an ecosystem that complements and extends existing industry practices (proof of evidence for relevance of impact that the SEM platform should demonstrate)
- Operation under an effective business model (proof of evidence for relevance of impact that the SEM platform should demonstrate)
- Good performance in terms of operational efficiency, reliability and costs (proof of evidence for relevance of impact that the SEM platform should demonstrate)
- Compliance with existing maritime safety standards and the capacity to create new ones (proof of evidence for relevance of impact that the SEM platform should demonstrate)

Breath of impact - Pathways to impact (the context within which impact takes place must be broader beyond research in the realms of the society, economy, public services, and quality of life)
- Social impact: SEM should address the very important societal challenge, which is the improvement of sea transport safety (quality of life etc.).
- Economic impact: SEM should provide to coastal shipping businesses operational efficiency and new ways to satisfy and serve the needs of their customers (passengers), thus increasing attractiveness and adoption rates
- Regional impact: SEM should support the destination development in the tourism industry, via a quality infrastructure, and decentralization outcomes conducive to regional development

5.2 Baseline environment

Objective: Understanding the environment where the SEM platform will operate, in terms of existing operation and facilities, stakeholders' attitudes and problems-to-solve.

Reference material: The workshop organized by the Univ. of the Aegean with the participation of the major research projects in the area of evacuation management | The Digital Transformation of the Evacuation Process in Passenger Ships (Nov 2022) | Agenda & presentations available at: [Workshop (Online): The Digital Transformation of the Evacuation Process in Passenger Ships | Futurium (europa.eu)]

What is currently in place
- Well defined evacuation processes but no technology-assisted
- Manual coordination effort
Key stakeholders and how they may affect the change, i.e., the implementation of the SEM platform
- SEM platform promoters
- Coastal shipping business: neutral
- Land-based control authorities: eventually positive
- Public Policy organizations: positive in the long run
Issues raised in past evacuations (evacuation performance “problems-to-solve”)
- Delays of the announcement of the alarm
- Absence of further guidance and information from the Bridge side
- “Irrational” behavioral patterns of the passengers (panic and paralysis)
- Passengers trapped in specific areas (cabins, corridors, garages etc,)

5.3 Pilot primary and secondary impact objectives

Objective: Breaking the assessment into more manageable tasks of validation in the light of the expected social, economic and regional impact.

Reference material: Analysis within Task 8.6 (Pilot evaluation, Lessons Learnt, Recommendations and Best Practice) - a combination of research, observations and interviews.

Pathway to impact	Expected outcome	Primary or Secondary
Social (S)	Increase passengers safety via the acceleration of evacuation-mustering processes	P
	Reduce the usually high number of fatalities observed in cases where the evacuation process is not working	P

	properly	
	Handle correctly and quickly eventual passengers' injuries during the evacuation process	P
Business (B)	Promote the Platform to potential adopters (coastal transport businesses)	P
	Operate the platform under a "shared responsibility model" where a core processing component "in the middle" (via collective funding), deployed on-land, connects to ship-specific on-board infrastructure networks (WiFi/beacons and 5G infrastructures)	P
	Complement and extend/improve the existing evacuation process with a medium-size technology investment	P
	Increase evacuation performance and evacuation process reliability, therefore improve compliance with the safety regulation	P
	Re-use of the SEM platform to provide value-added services (location and identity based services and payments) to passengers	S
Regional (R)	Improve the tourist attraction of a region by increasing the safety perception of the visitors	S
	Improve decentralization in coastal areas via transport safety	S

5.4 Impact scoring

Objective: This stage of the methodology concludes on the implementation of the Impact Assessment Framework, It essentially proposes a report of impact activity based on the definition of Indicators for each Impact outcome and an Actual vs. High Performance Scorecard (completed by the WP8 team).

Reference: Previous sections and tables.

Impact outcome	Key stakeholder	Impact indicator	Actual performance scorecard (1-10)
1. Increase passengers safety via the acceleration of evacuation-mustering processes (S-P)	a. Land-based control authorities b. Coastal shipping business	Reduce the evacuation-mustering time by 10% (minimum)	8

		Monitor and control the evacuation process	8
2. Reduce the usually high number of fatalities observed in cases where the evacuation process is not working properly (S-P)	a. Land-based control authorities b. Coastal shipping business	Quickly move passengers to mustering stations	8
		Instantly identity evacuees	9
3. Handle correctly and quickly eventual passengers' injuries during the evacuation process (S-P)	a. Land-based control authorities b. Coastal shipping business	Identify passengers at risk	9
		Reduce Incident (during evacuation) Response Time	9
Actual vs. High Score			51/60

Impact outcome	Key stakeholder	Impact indicator	Performance scorecard (1-10)
4. Promote the Platform to potential adopters (coastal transport businesses) (B-P)	a. Coastal shipping business	Platform readiness	7 (weak)
		Industry awareness	6 (weak)
5, Operate the platform under a “shared responsibility model” where a core processing component “in the middle” (via collective funding), deployed on-land, connects to ship-specific on-board infrastructure networks (WiFi/beacons and 5G infrastructures) (B-P)	a. Land-based control authorities b. Coastal shipping business c. Public policy organizations	Public-private partnership model analysis	6 (weak)
6. Complement and extend/improve the existing evacuation process with a medium-size technology investment (B-P)	a. Coastal shipping business	Willingness of the industry to further invest in safety management	6 (weak)
7. Increase evacuation performance and evacuation process reliability, therefore improve compliance with the safety regulation (B-P)	a. Coastal shipping business	Industry perception of the benefits from adopting the Platform	8
8. Re-use of the SEM platform to provide value-added services (location and identity based services and payments) to passengers (B-S)	a. Coastal shipping business	Platform capacity to deliver value-added services (Secondary objective: max 9)	8
Actual vs. High Score			41/59

Impact outcome	Key stakeholder	Impact indicator	Actual performance scorecard (1-10)
9. Improve the tourist attraction of a region by increasing the safety perception of the visitors (R-S)	a. Public policy organizations	International press coverage (Secondary objective: max 9)	6 (weak)
10. Improve decentralization in coastal areas via transport safety (R-S)	a. Public policy organizations	Local and Tourist population dispersion (Secondary objective: max 9)	7
Actual vs High Score			13/18

In summary:

- Social impact score: 51/60 (85%)
- Business impact score: 41/59 (69.5%)
- Regional impact score: 13/18 (72.2%)
- Total impact score: 105//137 (76.6%)

5.5 Future action

Indicators with weaker scores	Actual score	Action to be undertaken to improve score
Platform readiness	7	**Integration of SEM Platform with VDES | VHF DATA EXCHANGE SYSTEM system from Thales/Italy (connected ship - emergency communication infrastructure)** (*) Decided 10.3.2023 Reference: G1117 VHF Data Exchange System (VDES) Overview - IALA AISM (iala-aism.org)
Industry awareness	6	**Issuance of a Smart Evacuation Management NFT (Non-Fungible Token) to raise public funding** (*) Launch time: Spring 2023 (**) In collaboration with AQIFI | Aqifi -
Willingness of the industry to further invest in safety management	6	

		The Open Bridge Between Web 2.0 and 3.0 References: - How NFTs Are Creating Social Value (forbes.com) - How scientists are embracing NFTs (nature.com) Example: - Cointelegraph's NFT collection curated by you
International press coverage=	6	
Public-private partnership model analysis	6	**The implementation of SEM Platform as a joint public-private initiative, incl. business model and costs, has been investigated by the Univ. of the Aegean (see: Annex 6) -- see also: PALAEMON WP9 Exploitation Plan** (*) Further investigation in progress, in collaboration with the Municipality of Piraeus

5.6 Framework validation

The methodology framework has been validated as the developers of the methodology state in the paper where they describe their methodology[30]:

"A. Guidance: The framework was informed by the guidance of the G8 Social impact and investment Forum (Impact Taskforce, 2014), REF2014 (REF, 2014), REF2020 (HEFCE, 2017), and Economic and Social Research Council (ESRC, 2017).

B. Comparison: The framework was compared to similar impact assessment frameworks from selected research projects such as: a) AMITRAN Project, funded by the European Commission (Mahmod, Jonkers, Klunder, Benz, & Winder, 2014) and, b) Investment Facility Project (IF), funded by the European Investment Bank (EIB, 2005) c) Vitae Impact Framework (Bromley & Metcalfe, 2012)?

[30] Ibid.

ANNEX 1: Overview of piloting scenarios/exercises

This ANNEX contains an overview of the piloting scenarios and exercises that were executed on ELYROS F/B and are described in detail in D8.2b Chapter 4.3 "**Piloting actions**". The pilot simulated a fire emergency scenario onboard ELYROS to test the entire emergency handling process, from emergency detection to mustering of passengers and handling passenger incidents. The PALAEMON SEM platform was used to coordinate the crew's responses and track the location of each crew member and provide real-time information on their status as well as the status of the emergency. The bridge was able to review all available information to evaluate the situation and take action accordingly. Various other passenger-related incidents were also simulated, to evaluate the capabilities of the SEM platform.

This core PALAEMON SEM Pilot Plan was decomposed into various pilot exercises with clear steps and outcomes. In detail, the core pilot plan was composed of three pilot groups of exercises namely, **Pre-evacuation**, **Mustering & Evacuation**, and **Issue/Incident Management**. These groups were based on the corresponding evacuation phases and involved a variety of pilot exercises, each exercise consisting of key pilot actions that are outlined in the section below.

Table 18. Pilot Scenarios and Exercises

1st Pilot Group (Pre-evacuation)	2nd Pilot Group (Mustering and Evacuation)	3rd Pilot Group (Issue/Incident Management)
Pre-evacuation 1	Must_311	Must_321
Pre-evacuation 2	Must_312	Must_322
	Must_313	Must_323
	Must_314	Must_324

The first group, Pre-evacuation, encompassed **two pilot exercises**: Pre-evacuation 1 and Pre-evacuation 2. The Pre-evacuation 1 pilot exercise entails conducting an assessment on the capacity of the SEM platform to detect an emergency and its ability to improve the coordination with respect to dispatching the firefighting team. Pre-evacuation 2 entails conducting an assessment on the capacity of the SEM platform to coordinate the crew to assume their designated evacuation positions before the General Alarm (GA) is initiated.

The second group, Mustering & Evacuation, included one **pilot exercise**, namely Mustering 1, which comprises four pilot actions, namely Must_311, Must_312, Must_313, and Must_314. Must_311 was designed to enable the assessment of the capacity of the SEM platform to implement and activate an Augmented General Alarm. This action item also involved directing the movement of a group of passengers from a specific area to their designated muster station. Must_312 was designed to provide an assessment of the capacity of the SEM platform to update the evacuation plan of the vessel in real time, instructing passengers to follow alternative escape routes (to avoid hazardous areas) while directing them to their assigned muster station. Must_313 was defined to provide an assessment of the capacity of the SEM platform to handle unexpected events during a mustering process. Specifically, this action item dealt with a ‘rogue’ passenger leaving the muster station and the detection and handling of this event by the SEM platform. Finally, Must_314 entailed conducting an assessment of the capabilities of the SEM platform to assign evacuation groups to passengers in preparation for embarkation.

The third group, Issue/Incident Management comprises one **pilot exercise**, namely Mustering 2 which includes four action points, namely: Must_321, Must_322, Must_323, and Must_324. Must_321 enabled the assessment of the SEM platform capacity to detect and provide assistance to a trapped passenger who has requested help via the Palaemon App. Must_322 was designed to provide an assessment of the capacity of the SEM platform to detect an unexpected health issue and involves the dispatching of a medical team. Must_323 was defined to provide an assessment of the capacity of the SEM platform to assist passengers with special requirements.

ANNEX 2: SEM Platform Simulations

Chapter 5 of D8.1b provided a detailed account of the Smart Evacuation Management (SEM) simulations, which were conducted to evaluate the effectiveness of the SEM platform in the context of ELYROS. The purpose of conducting the SEM platform simulation testing was to confirm that the system was prepared for deployment on ELYROS for piloting. The validation process ensured that the SEM platform was capable of handling an emergency situation that could occur on the ship, providing the user with all necessary information regarding the progression of the mustering. Specifically, the simulation exercises verified that the SEM platform achieves the following objectives:

Table 19. Simulation Objectives

Simulation Objective	Description
SO1	handle the **large volume of location data** generated by hundreds of passengers moving inside the spaces of ELYROS during the mustering process
SO2	generates the **correct mustering instructions** for the passengers based on their current (simulated) location
SO3	provides **accurate passenger counts and identification** in assembly stations via user-friendly UIs.

To achieve the aforementioned objectives the methodology of performance testing was adopted. Specifically, Performance testing is a type of software testing that is used to evaluate the performance characteristics of a system, application or component, such as scalability, stability, and resource usage. The goal of performance testing is to ensure that the software can handle the expected workload and user traffic, and that it meets the performance requirements that were specified.

Performance testing can take many forms, including load testing, stress testing, and endurance testing. Load testing is used to measure the system's behaviour under normal or expected workloads. Stress testing is used to measure the system's behaviour under extreme or unexpected workloads. Endurance testing is used to measure the system's behaviour over an extended period of time to ensure that it can maintain performance and stability over time. During performance testing, test cases are designed to simulate real-world usage scenarios and are executed using automated testing tools or manual testing methods. The test results are then analysed to determine if the system is performing as expected and if there are any bottlenecks or issues that need to be addressed. For the PALAEMON SEM platform, **load and stress testing** were combined as the normal and extreme workloads are identical (meaning the same number of passengers is generating data in the system in all cases).

To verify the proper functionality of the SEM platform under load testing, specific software was developed (**PaMEAS Passenger Location Simulator**) to simulate the movement of passengers on board the ship. In detail, this software was used to simulate the movement of **700 passengers** on board the decks of ELYROS, starting from random locations on the decks of the ship and heading towards their assigned muster station.

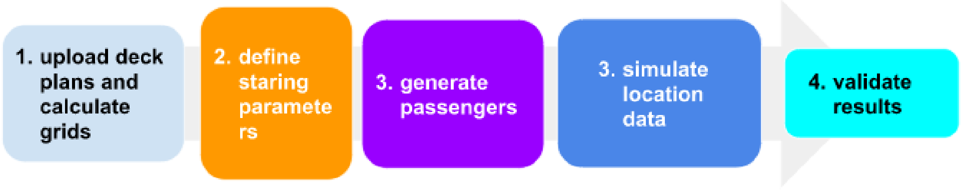

Figure 8. Passenger Simulator Execution Flow

The movement of passengers onboard ELYROS was simulated using the vessel's floor plans to create a grid with walls acting as blocking barriers. The grid was then inputted into the simulation software that randomly generated the passengers at various starting locations and utilized the A*-algorithm[31] to determine their path to their designated muster stations. Additionally, the software enables the random assignment of movement speeds to the passengers and allows for the specification of the percentage of passengers who require evacuation assistance or will display health issues.

Table 20. Simulation Stages

Simulation Input	Simulation Execution	Simulation Finish
• Vessels floor plan • Initialization parameters (percentage of passengers to exhibit health issues)	• Virtual Passenger Generation • Path Assignment • Speed Assignment • Movement Simulation • Tester triggers events (e.g. mustering instructions)	• Virtual Passengers gathered at MS

Once the paths are assigned, the simulation software continuously broadcasts new location data for each passenger to the PALAEMON SEM platform every 3-5 seconds, ensuring that the passengers adhered to their predetermined path. Passengers with mobility issues remain stationary while passengers exhibiting abnormal behavior start moving and eventually exhibit incidents before reaching the muster station.

As a result using this software it is possible to ensure that the SEM platform can cope with large volumes of data, correctly updating the location of passengers as these are generated by the simulator and monitor the progression of the mustering. Furthermore, using the simulation software, it is also possible to validate key functional requirements of the SEM platform. Specifically, through the SEM platform's user interface, emergency

[31] The A* algorithm is a popular path finding algorithm commonly used in computer science and game development to find the shortest path between two points on a grid

alerts and mustering instructions can be initiated and transmitted to the users. The platform logs the transmission of these messages, allowing users to verify that the transmitted instructions adhere to the ship's emergency plan. Finally, the functionality of the SEM platform UIs can be validated using the simulated passenger location data and to evaluate the platform's capacity to oversee the progression of the mustering process in a comprehensive and user-friendly manner.

ANNEX 3: Evaluation Metrics Measurements

This section presents the methodology used to measure the metrics described in the previous section as part of specific pilot actions and the results obtained for each metric. Specifically, for the measurement of these metrics three types of methodologies were used: eye-tracking software (for EVRTI and EVPDI), stopwatch measurements (for EVRTI, EVPDI and IRTI) and system log analysis.

Eye-tracking software. Eye-tracking software is a technology that allows researchers to measure where and how users look when interacting with a specific system. By tracking the gaze of the users, eye-tracking software can provide insights into how users interact with the content by generating heatmaps from the eye-tracking data. Heatmaps are visual representations of user attention that show in which areas of the screen the users spend the most time on and help identify usability issues, design preferences, user expectations, and more.

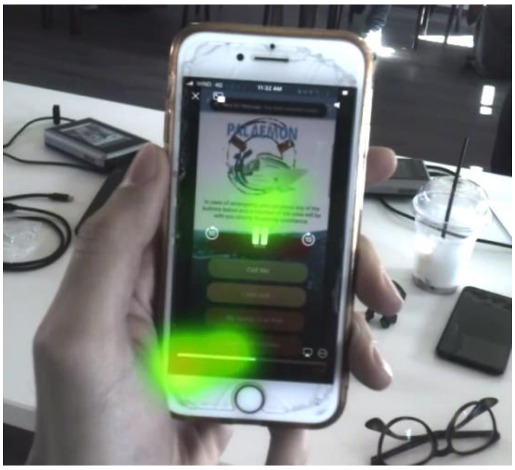

Figure 9. Eye Tracking software heatmap during tests

The process of extracting measurements using the eye-tracking goggles is presented in the following figure (Figure 9).

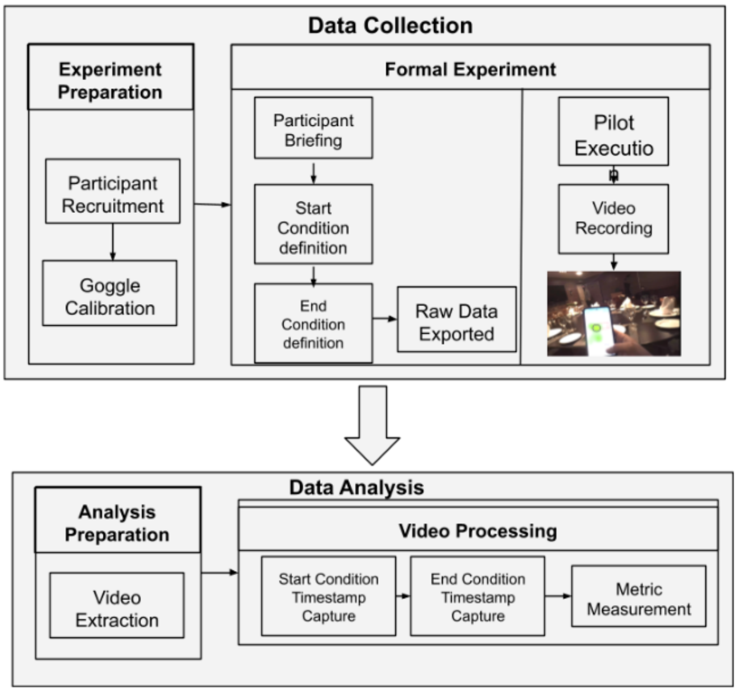

Figure 10. Eye Tracking software Metric Measurement process.

Specifically, initially the participants are recruited and for each participant a calibration of the eye-tracking goggles is executed. This ensures an accurate recording of the heatmap for each user. Next, all the participants were gathered and briefed about the context of the pilot exercises. Following this briefing, the start and end conditions signifying each measurement were defined as described in the following table (Table 21).

Table 21. Metrics initialization and termination conditions using eye-tracking goggles

Metric	Start Condition	End Condition
iper	User picks up their phone to read the emergency alert message	User is prompted to take action by either standing up or (if already standing up) stops looking at their phone
pireach	User starts reading the mustering instructions	User starts walking/running towards the muster station

After the definition of the measurements conditions, the actual pilot is executed with the participants wearing the eye-tracking goggles. The eye-tracking goggles record video footage of all the actions the participant makes during the exercise. The footage is then extracted into a suitable format and analysed by experts to conduct the measurements (using timestamps from the footage of the start condition and end condition) for each relevant metric.

Stopwatch methodology. This methodology of executing measurements resembles to a great extent the actions described with the eye-tracking goggles with the key difference of a trained pilot execution team member monitoring the actions of the subjects and taking the measurements of the metrics in real time. This type of measurement provides a greater degree of flexibility as the behaviour of groups can be monitored using a single measurement. Specifically, the process of extracting measurements using the stopwatch methodology is presented in the following figure (Figure 11).

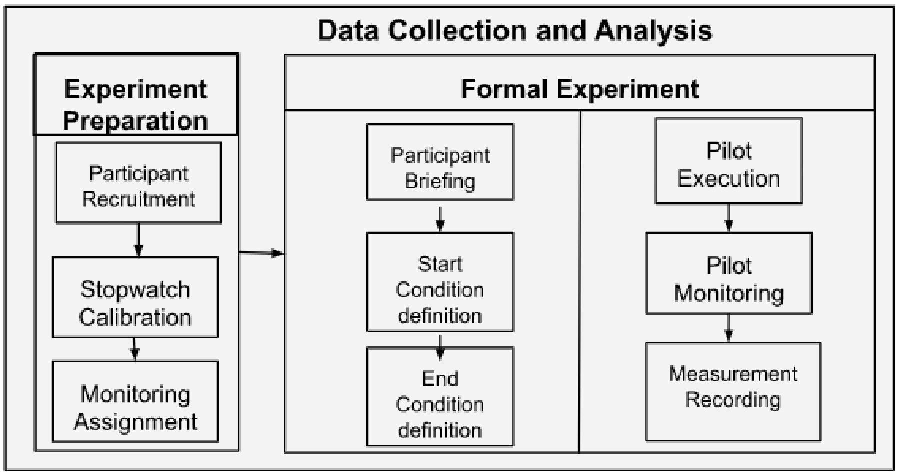

Figure 11. Stopwatch Metric Measurement Process

Specifically, initially the participants are briefed on the pilot exercises and the members of the team responsible for conducting the measurements are also briefed as to the start and end conditions of their measurements. Additionally, the team members responsible for conducting the measurements are assigned to specific groups of passengers, crew members or placed at the bridge. Finally, during the execution of the pilot exercises the monitoring team members take measurements using their stopwatches of the start and end conditions of the metrics. Using this methodology the following metrics were measured.

Table 22. Metrics initialization and termination conditions using stopwatches

Metric	Start Condition	End Condition
iper	User picks up their phone to read the emergency alert message	User is prompted to take action by either standing up or (if already standing up) stops looking at their phone
pireach	User starts reading the mustering instructions	User starts walking/running towards the muster station
idetect	User requests help using	-

	their Passenger mobile app	
iasgmt	Crew assignment proposition displayed on the bridge UI and is reviewed by the officer on monitoring the UI	-
itrav	Assigned crew member arrives at the location of the passenger that requested assistance	-

System Log Extraction methodology. The SEM platform maintains logs of the location of the passengers, as well as timestamps for the transmission of specific messages to the passengers and crew members. As a result, analysis of these logs can be used to extract measurements of specific actions of the passengers during the piloting exercise which correspond to the metrics defined in this section. This methodology proved useful in making measurements on the last piloting action (for which, due to the presence of end users and filming crew members, the aforementioned methodologies were not applicable). In detail, the methodology of extracting metric measurement from the SEM platform logs is presented in the following figure (Figure 12).

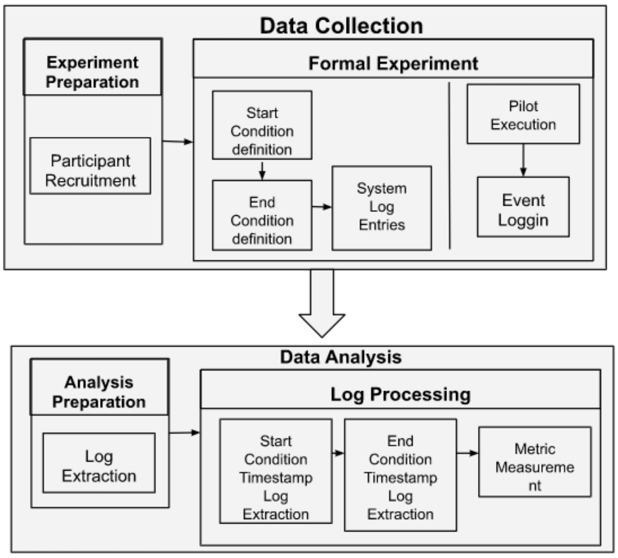

Figure 12. Log Extraction Metric Measurement Process

Specifically, using this methodology after the recruitment of the end users the start and end conditions for the log extraction measurements are defined. Then, the pilot actions are executed as normal and the SEM platform generates the appropriate logs for the movement of the passengers inside of ELYROS as well as the times of the transmission of alert, and mustering notification messages to them. Next, after the execution of the pilot these logs were extracted and the timestamps of message transmissions were compared with the movement of the passengers. Specifically, the start and end conditions for the metrics measurements using this methodology are defined in the following table (Table 23).

Table 23. Metrics initialization and termination conditions log extraction

Metric	Start Condition	End Condition
iper	User picks up their phone to read the emergency alert message	User is prompted to take action by either standing up or (if already standing up) stops looking at their phone
pireach	User starts reading the mustering instructions	User starts walking/running towards the muster station

ANNEX 4: Recommendations from the experts in detail, prior of the pilot development

This annex contains as bullet points the recommendations made by the expert users during the remote workshop demonstration of the SEM platform prior to its final iteration and denotes whether the recommendations were implemented in time for the final pilot action onboard ELYROS.

Table 24. Expert User Recommendations

#	Recommendation	Updated in time for pilot
1	Changing the wording from “recommendation” to “advice”	yes
2	The term “sound general alarm” should be rephrased	no
3	The meaning of the action “sound general alarm” should be used in the right way. The activation of the general alarm in fact means that no other option then leaving the ship is possible.	yes
4	DSS should adhere to the IMS/SOLAS regulations	yes
5	DSS should be implemented as a checklist. The way it appears now is confusing to the end users. The checklist should contain the options: “yes/no/not applicable” for the proposed actions.	no
6	Hard copy documentation about the actions taken are still mandatory and cannot be substituted.	n/a
7	DSS should always display the type of the incident (e.g. type of fire).	yes
8	The wind directions in the Weather Forecast Toolkit should be displayed as a compass instead of text.	no
9	The location of the fire should be displayed on the map.	no
10	Bigger fonts, less text and more visual information should be used.	yes
11	Only the crew members are displayed on the map prior to the general alarm. However, the information about the passenger’s location might be interesting for crew members.	yes
12	In general, oral information (face to face or Walkie-Talkie) instead of messages is the preferred communication method. Thereby misunderstandings can be prevented and the communication process is quicker. In addition, simple pictures with colours should be used for being better and quicker understood in emergency situations.	yes

13	Information should be kept short and simple. If messages are sent, they only should be addressed to management level. Crew members on operational level do not have the capacity to read/understand the messages most of the time.	yes
14	It is not recommended to inform passengers about the type of the incident. They do not need to know this information as it might confuse/scare them. When sending messages to passengers they should only know that mustering starts, which equipment is necessary (e.g. life vests and warm clothes) and that the action is not a drill. No further details or explanation is needed. Passengers will receive more information about mustering at the muster station.	no
15	When sending messages to passengers, the information should be displayed in pictures and colours, not in text. Pictures and signs are processed much faster than text.	yes
16	An option for reopening the muster station should be available for assigning new passengers.	yes
17	The monitoring of the congestion on the decks is not relevant for the mustering phase.	no
18	The capacity of MEVs must be seen to verify next steps and set measures.	no
19	Show the status of the stations in an overview and the information about missing passengers could be optional. The captain should have the information, which passenger is in whose responsibility as well as the mobile number of the crew member, but not about details of the profile.	yes
20	Clicking on a Muster Station, could open the map to that MS. A combination of letters and numbers would make it easier to locate and identify the muster stations.	yes
21	Information about the passengers at the muster stations after completing the mustering process should be limited to the	yes

	number of full and still available muster stations.	
22	Although the pilot will take place on a ferry, the procedure has to be adopted, because the PALAEMON project addresses only cruise ships. Therefore, the “Embarkation” phase and as a consequence, sending messages to passengers, has to be removed.	no
23	The last phase serves as a finish line for demonstration purposes and not for a real scenario.	yes

ANNEX 5: Interviews with experts during the pilot deployment

Interview 1. Nikolaos Ventikos, NTUA

- Role: Associate professor at National Technical University of Athens, School of Naval Architecture and Marine Engineering
- Background: Naval architect and marine engineer, leading the Maritime Risk Group which is part of the Laboratory of Maritime Transport and Marine Safety
- Positive and innovative points of PALAEMON project: integration of new technologies into legacy procedures, providing a comprehensive and accurate picture for decision-making, giving the captain the possibility to take the right decision and act properly when this is needed
- Integration of data and services rating: 8 or 9 out of 10, with room for improvement as we need for more sensors and data sources
- Situation awareness rating: 9.5 out of 10, providing crucial feedback and information for decision-making during emergency situations such as where the people are, what is going on, weather we have people disabled people that need immediate assistance
- User friendliness rating: PALAEMON is user-friendly, providing necessary information and a good overview of various types of information, localization of people, and risk levels on different decks.

Interview 2. Antonis Triantafyllou, ANEK

- Role: Served as Designated Person Ashore (DPA) in ANEK for almost 5 years
- Background: More than 15 years as a chief engineer at sea and over 20 years as a DPA
- Positive and innovative points of PALAEMON project: the system can be a useful tool for passenger and vessel safety and can solve problems that have existed for decades, such as managing large numbers of passengers in emergency situations
- Integration of data and services rating: 8 out of 10, as there is always room for improvement
- Situation awareness rating: 9 out of 10, as it provides accurate and useful data
- User-friendliness rating: 8 out of 10 as he is unsure how it will work with passengers using cell phones or smart bracelets

Interview 3. Vasilis Papadopoulos, HMOD

- Background and role: Former colonel of the air force, worked on horizon projects in HMOD, and dealt with safety and port protection in the Hellenic air force
- Positive and innovative points of PALAEMON project: Enhances fast evacuation, provides awareness to captain and crew, exchanges accurate information among crew and passengers, and has potential use in other sectors managing large groups of people
- Integration of data and services rating: 9.5 out of 10 as it is a well-designed and expandable system (rated based on system details and capabilities)

- Situation awareness rating: 9.5 out of 10, as it provides good awareness and accurate information to crew
- User-friendliness rating: 9.5 out of 10, as it is a very user-friendly tool for both crew and passengers

Interview 4. Periklis Stasinos, Ericsson

- Background and role: Representing Ericsson as project manager in PALAEMON project. Ericsson was a technical partner of the project responsible for providing the radio access network which is a 5G standalone network.
- Positive and innovative points of PALAEMON project: Easy deployment of the network, end-to-end success of the project, good results for end-users, and successful trials. The 5G network deployed for the needs of PALAEMON is a private network that can be used by any business/organization offering ultra-low latency and higher beat rates. It boosts both capacity and coverage which is very important for applications that require accurate and fast access to data like PALAEMON.
- Project impact on companies: PALAEMON helped with exploitation inside the company and provided worldwide experience via useful use cases and end-to-end applications for the telecom industry.
- Market outlook: Market is not mature yet but expected to grow with time as the network opportunities increase.

Interview 5. Margarita Karagiorgi, ANEK

- Background and role: Second officer in Elyros ship, working for 10 years in ANEK
- Positive and innovative points of PALAEMON project: PALAEMON can decrease the time of evacuation which is very important, helps in managing passengers and crew and provides location and other useful information to the captain
- Situation awareness rating: 9.5 out of 10, as it is very helpful to have all info in one computer
- User friendliness rating: 9.5 out of 10, as it is very good and hopes it becomes reality in the near future

Interview 6. Nadège Llanes, Airbus

- Background and role: Worked previously as a ship captain, now working in Airbus with deep knowledge on maritime domain, awareness, and surveillance
- Positive and innovative points of PALAEMON project: Impressed with the demonstration, convinced that the system can efficiently evacuate passengers on board, and believes it is adequate for passenger safety
- Points that could have been better managed: Not mentioned
- Acceptability by companies and market outlook: Short term market, but compliance with international maritime laws and validation by organisms and classification societies such as IMO needed as the system should be considered a decision support system and should follow the rules of SOLAS and safety law.

- Integration of data rating: 8 out of 10
- Situation awareness rating: 9 out of 10
- User friendliness rating: 9 out of 10

Interview 7. Nikos Kintzios, Hellenic Navy Officer (ret)

- Role: Retired captain engineer from Hellenic Navy. Trained in firefighting, rescue at sea and assisting other ships in Portsmouth, UK.
- Background: Rescue and assisting ships
- Positive and innovative points of PALAEMON project: The system is useful and the demonstration of the system's possibilities was impressive. It can be valuable for muster to manage crew and passenger evacuation and has possibilities for expansion with future sensor integration
- Integration of services and data rating: 8-9 out of 10, as it is the first attempt
- Situation awareness rating: 9 out of 10
- User friendliness rating: 10 as it very important and has high expectations

ANNEX 6: SEM

Users' base: The SEM platform provides a cloud service which is accompanied by a sensing and communication infrastructure that should be deployed onboard the ship. Potential customers of the SEM platforms include: first, the shipping companies operating passenger ships and, secondly; second, the service providers of these companies, especially those providing satellite and mobile communication services in the context of the “connected ship”.

Value Proposition: The SEM platform allows a ship to overcome slow and disorganised crowd management, mustering and evacuation processes with people tracking, automated and semi-automated emergency alerts and notifications, continuous passengers counting and reporting to command team, “incident during evacuation” management via AI, and operations shared with the land-based control.

Challenges: The current version of SEM platform has successfully reached TRL 5 (Jan. 2023). However, a Minimum Viable Product needs a higher TRL that should be obtained through further research and pilot testing. A Smart Evacuation Management Research Infrastructure possessing the appropriate facilities, is therefore necessary to continue experimentation in an in-vivo environment, pilot tests with real users, the issue of new versions of the platform (starting from a minimum operation version), and to facilitate showcasing to investors and potential buyers.

The need of a research infrastructure has been also emerged as one of the conclusions from the online workshop, recently organized by PALAEMON and the Univ. of the Aegean, with the participation of the main EU projects in the area of digital transformation of the evacuation process, and researchers from Europe and abroad -- see: Workshop (Online): The Digital Transformation of the Evacuation Process in Passenger Ships | Futurium (europa.eu). Such a Research Infrastructure may also have the role of the innovation, interaction and co-production hub for similar projects and research initiatives in Europe and worldwide.

Users: The SEM platform provides a cloud service which is accompanied by a sensing and communication infrastructure that should be deployed onboard the ship. Potential customers of the SEM platforms include: first, the shipping companies operating passenger ships and, secondly; second, the service providers of these companies, especially those providing satellite and mobile communication services in the context of the “connected ship”.

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Further Development Costs: Devoted Costs = PM expensed * Partner Rate

Table 25. SEM Cost and effort

Cost Type	Time- PM	Cost (€)
Further asset development	36x4000	144.000 €
Business strategy Implementation	6x5000	30.000 €
NFT Promotion	6x5000	30.000 €
Other Costs* (incl. research facilities)		101.000 €
Oveaheads		75.000 €
Total initial investment	12	380.000 €

(*) Other costs=Cloud, software, hardware, etc.

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